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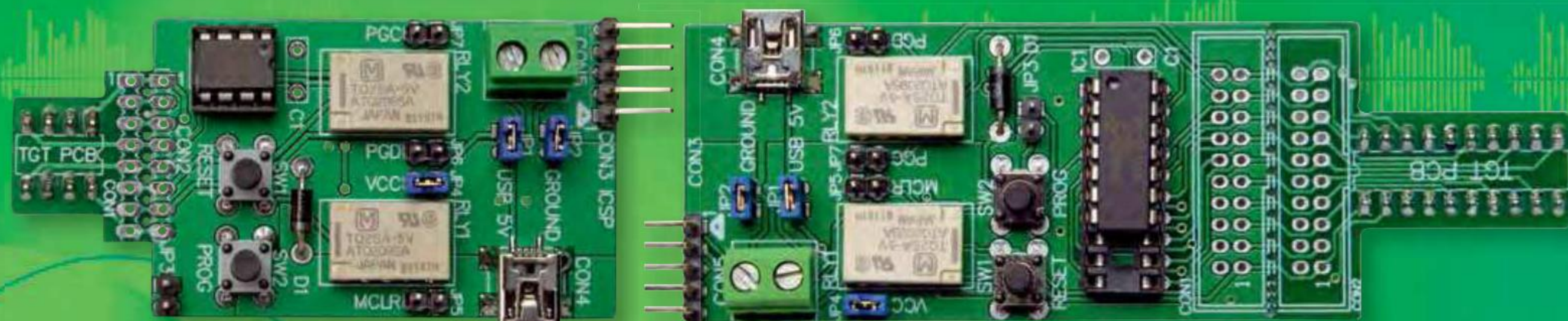
Distortion and distortion circuits

Audio Out

Designing a practical de-thump circuit

Make it with Micromite

Code for an iButton-based Electronic Door Lock



8/14/20-pin PIC Programming Helper



Full-wave Universal Motor Speed Controller

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Want exceptionally smooth speed control over the entire range for your power tool? This design is ideal for use with mains-powered motors rated up to 10A.

8/14/20-pin PIC Programming Helper by Tim Blythman 26
It's incredible what you can achieve with 8-pin PICs, but programming/debugging them can be a challenge. This board will make your PIC life much easier!

Advanced GPS Computer – Part 1 by Tim Blythman 32
Its 3.5-inch touchscreen makes our Advanced GPS Computer a great navigation tool on the road, in the water or even up in the sky. Plus, you can customise it.

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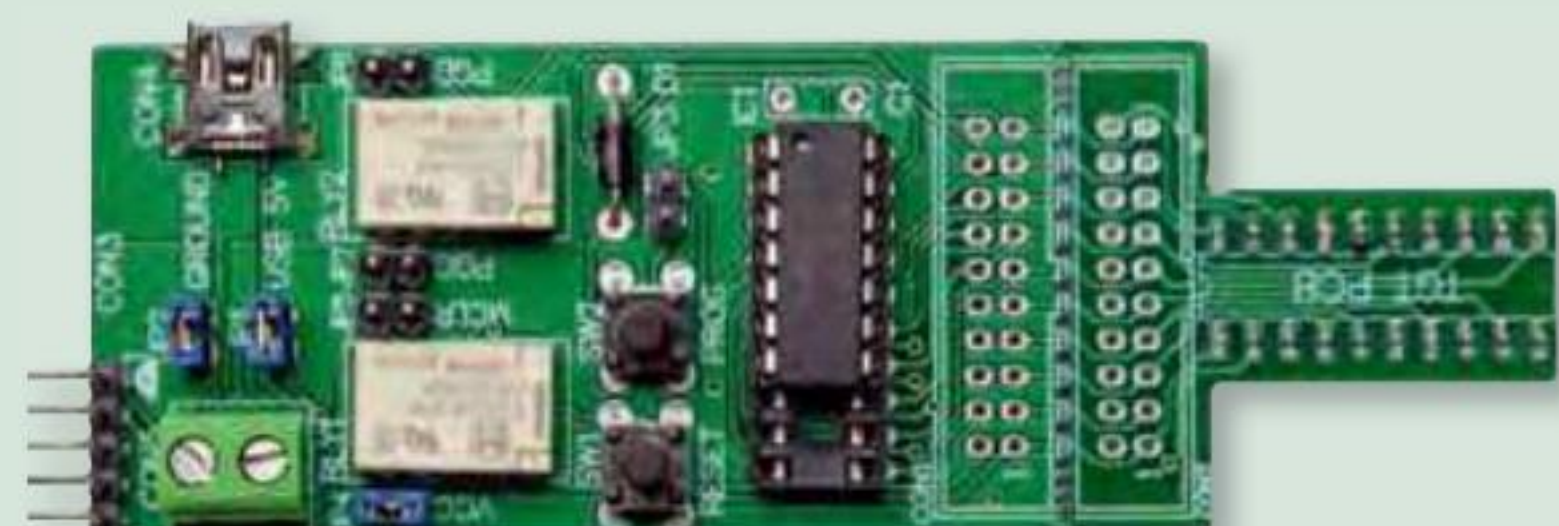
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The July 2022 issue of *Practical Electronics* will be published on Thursday, 2 June 2022 – see page 72.

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

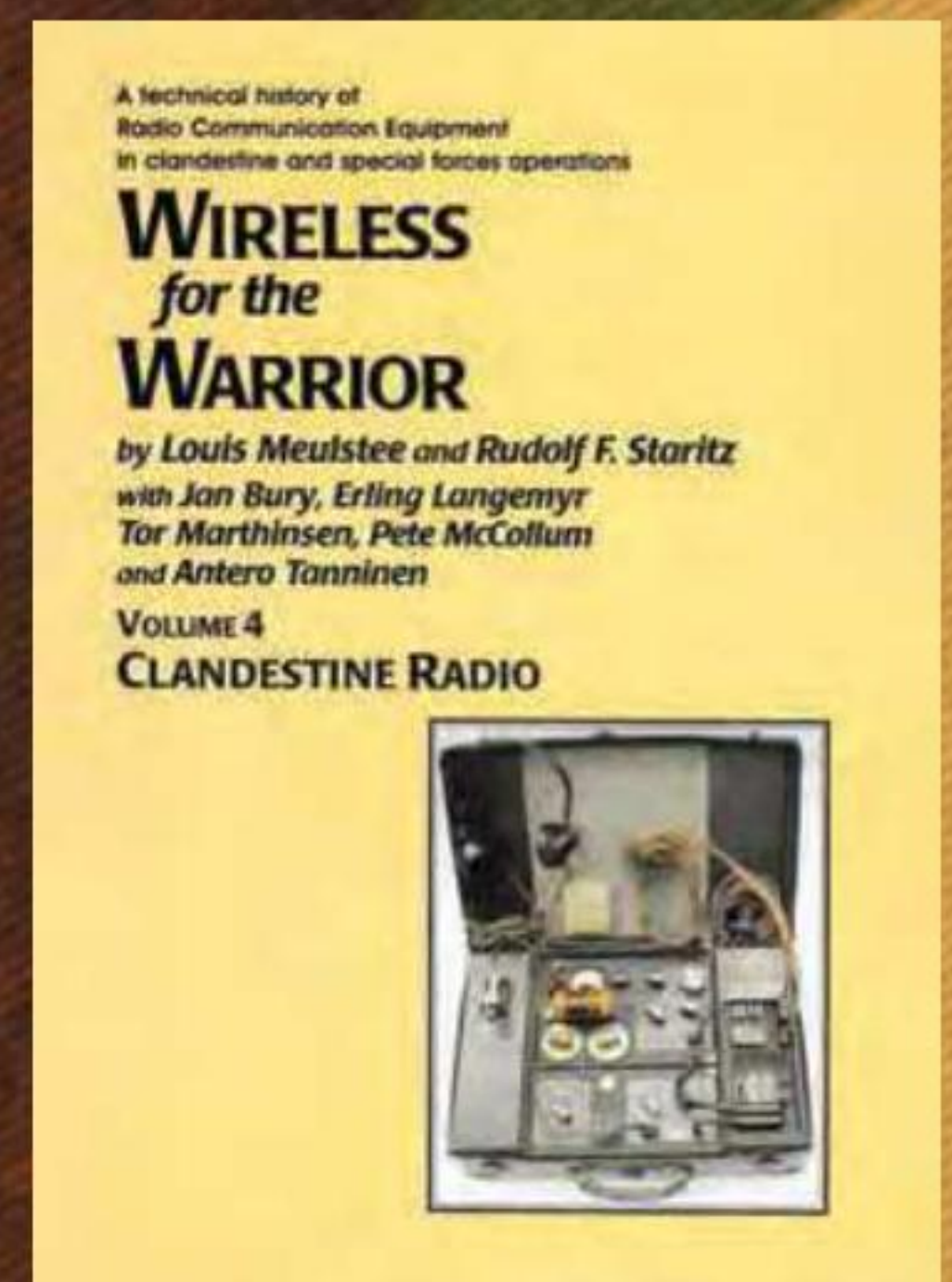
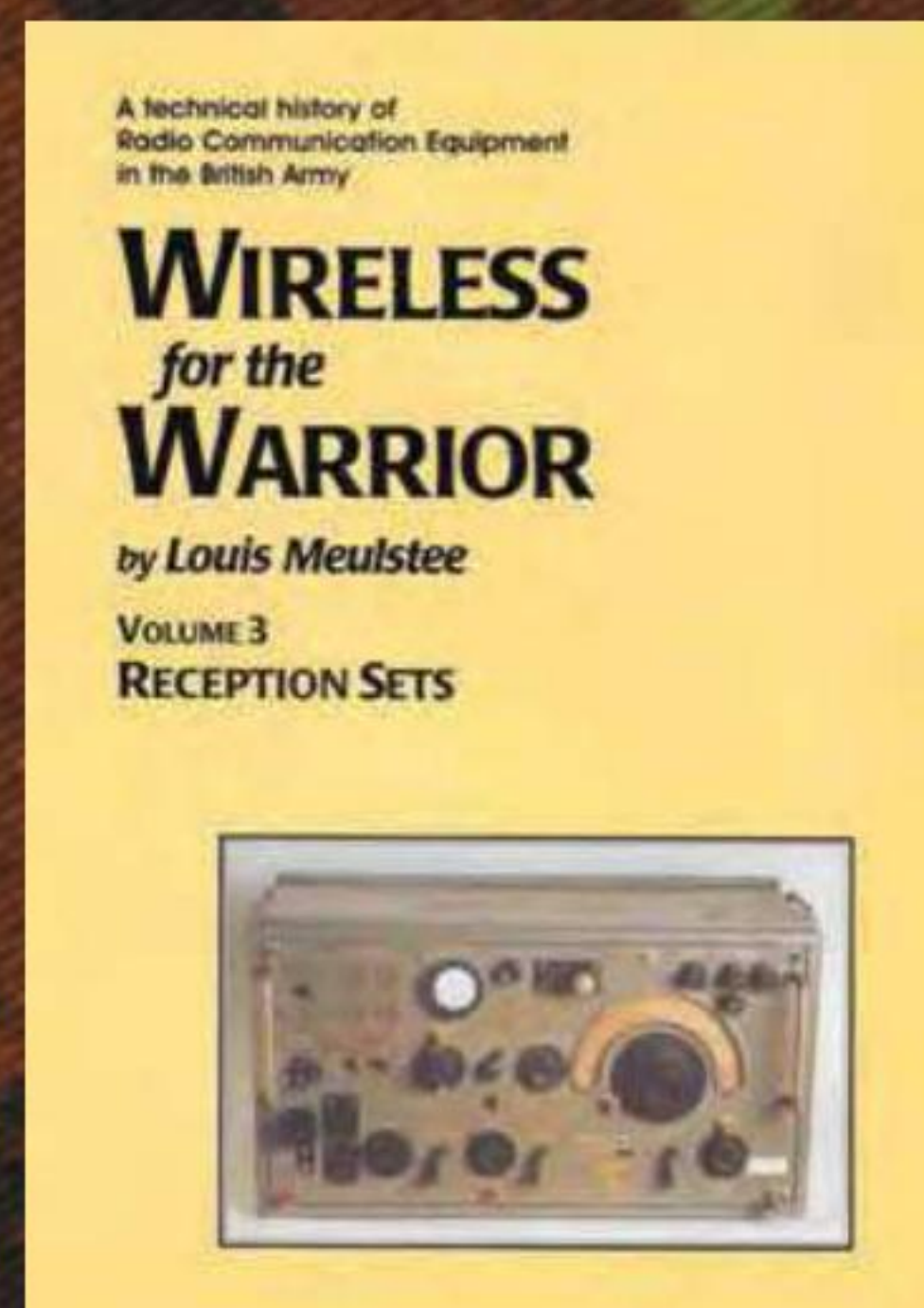
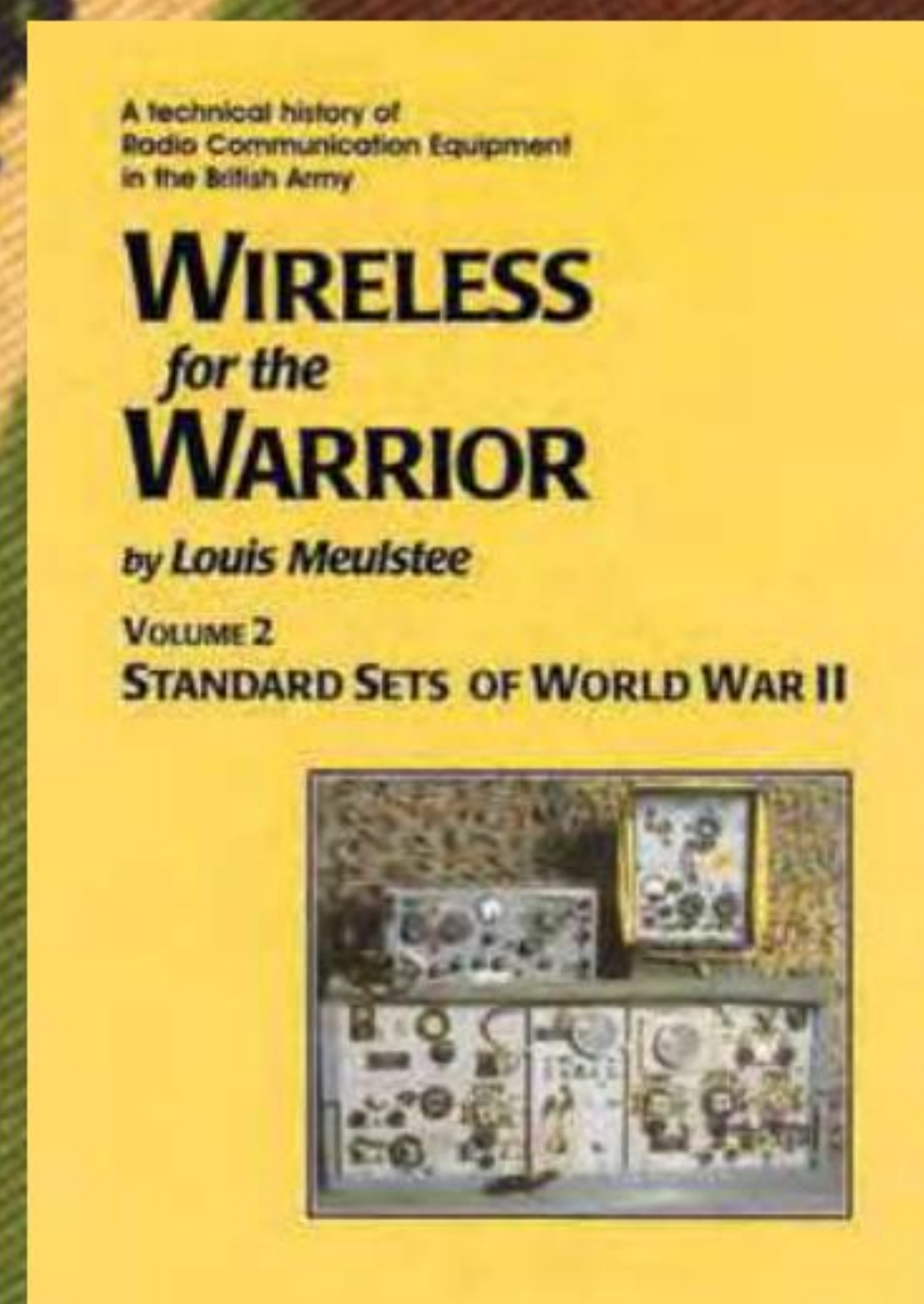
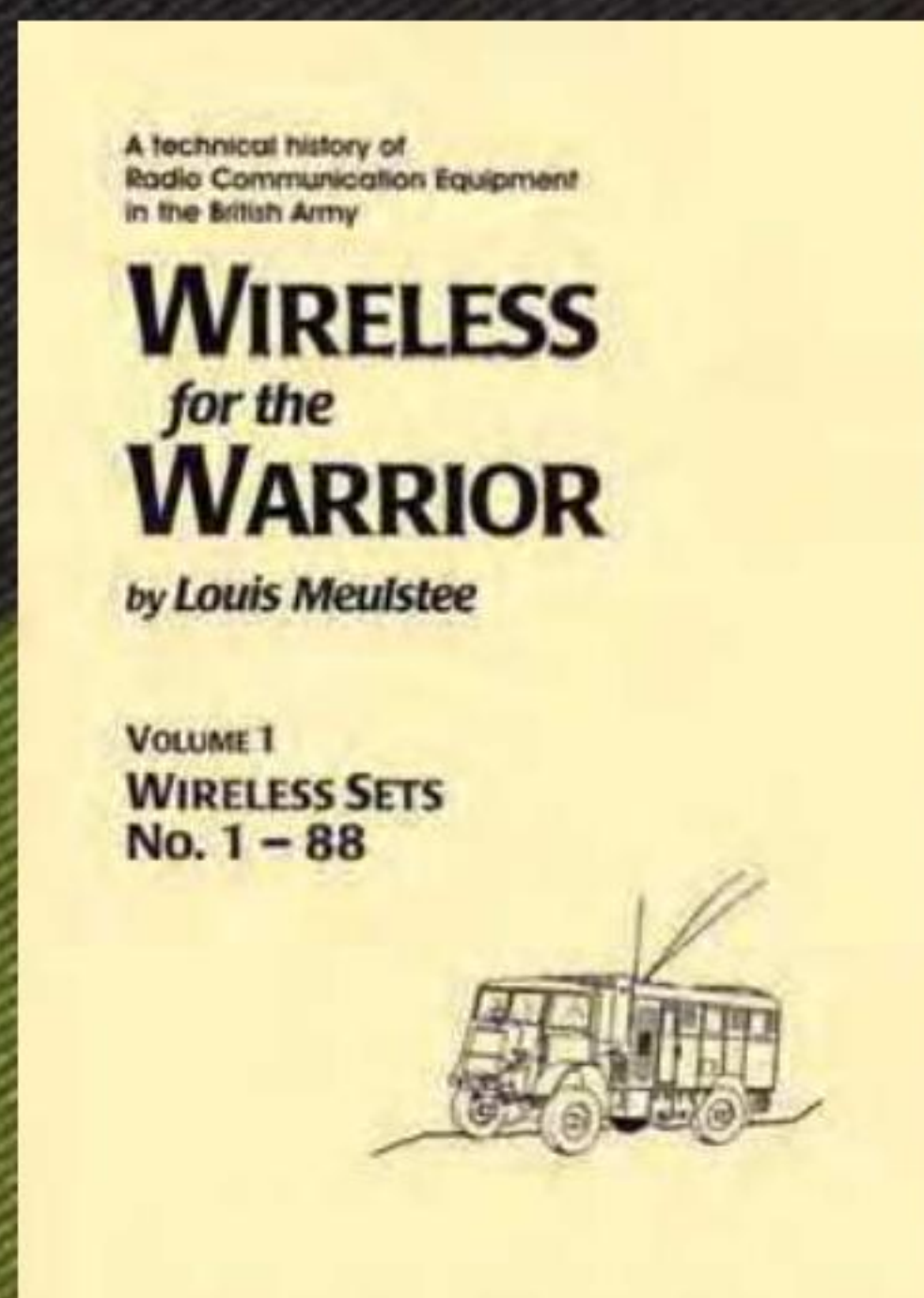
The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this

timeframe saw the introduction of VHF FM and hermetically sealed equipment.

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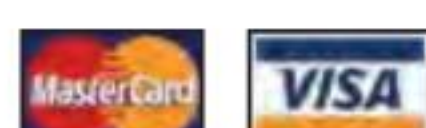
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How to annoy customers and lose them

I recently had a chat with my friend Steve, who is in the market for a set of Hi-Fi-quality headphones with both wireless and noise-cancelling capability. After considerable research he liked the look of a pair made by a well-known UK speaker manufacturer. He can be a little obsessive – in a good way – when it comes to researching expensive purchases, and was concerned that there seemed to be no obvious way to replace the headphone's rechargeable lithium polymer battery. LIPO is a good technology – long lasting and energy dense – but like all rechargeable batteries they have a limited lifespan, certainly much more limited than a pair of headphones. This worried him and he dug a little deeper.

Internet research showed this was a problem that others had faced, proving to be especially challenging if batteries died after the warranty had expired. They'd turned to the manufacturer for help, who offered to fix the problem for £299... on a pair of headphones that currently cost around £310 (as per Amazon). You can imagine the frustration of those reporting this problem on the web.

Distinctly underwhelmed with the UK approach, my friend tried a well-known and respected US rival. He emailed them and they replied that in their headphones, 'the battery is non replaceable'.

At this point, my friend turned to me because I already owned the previous generation of wireless headphones from the UK firm he initially liked. He asked if I knew about this problem. It was news to me, and somewhat irritated I decided to do my own research – but this time from an engineer's perspective. Had anyone on the Internet fixed a broken set of 'my' headphones, and how could I undertake a DIY battery replacement?

Just to be clear, we are not talking about tiny in-ear 'earbuds', but large over-ear headphones with plenty of space for normal-sized parts and which should – in theory – be fixable. Mine have soft leather pads that clip with magnets onto the speaker housing. Removing a pad reveals the thin speaker grill surrounded by even thinner stick-on fabric, but no way to get into the 'speaker cabinet'. However, someone on the Internet had discovered that scraping off a little of the fabric reveals assembly screws that give you easy access to the innards. In other words, a totally pointless application of a cheap sticky-backed material was there to deliberately mask how to fix a very expensive purchase.

It gets worse. The online repairer shared a photo of the battery in the headphones. It's nothing special; Amazon sell it for a tenner. In other words, a respected UK audio manufacturer now thinks it's good customer relations to charge £299 for five minutes work and a £10 part – thereby 'encouraging' you to buy new headphones, which presumably join the others in landfill two or three years hence.

Electronic waste is a global problem. Is it too much to ask that manufacturers design products that last, are genuinely fixable – and are honest about repair charges?

Matt Pulzer
Publisher

Positivity follows the gloom

Techno Talk

Mark Nelson

Is the premature death of LED lamp bulbs purely the result of user ignorance, or just the latest variant of a worldwide swindle that has been going on for nigh on a century? But on the bright side, is a Li-Fi revival possibly just around the corner?

There are some people who are convinced that the LED lamp bulbs of today (or at least some of them) are a swindle. In their opinion, these bulbs fail to deliver their claimed brilliance, get dimmer as they age or give up the ghost altogether long before the stated lifetime. Often, this is the result of user misunderstanding or unintentional mistreatment. A helpful and informative web page at <https://bit.ly/pe-jun22-led> goes a long way towards providing the user enlightenment that the industry should have provided – or maybe decided was in their interest to stifle!

It's not the first time!

Oddly enough (or perhaps entirely predictably if you're a conspiracy theorist), there's a precedent for short-changing buyers of lamp bulbs, and it began just two years short of a century ago. In those days, bulbs had the same form factor, used exactly the same bayonet and screw fittings and performed exactly the same function – only less efficiently. The sole major difference was that the bulbs were incandescent, as were their users when they discovered that most of the bulbs on sale were intentionally and deliberately designed to fail prematurely!

To quote researcher Markus Krajewski, 'On 23 December 1924, a group of leading international businessmen gathered in Geneva for a meeting that would alter the world for decades to come. Present were top representatives from all the major light bulb manufacturers, including Germany's Osram, the Netherlands' Philips, France's Compagnie des Lampes, and General Electric from the US.' But this was not a social event, but strictly business. They had come to Switzerland to found a worldwide cartel that they named *Phoebus*, after a sun god in Greek mythology. Enlightenment was, so to speak, its goal, but not in terms of classical education. Its stated aim was the 'development of lighting', but the sole beneficiaries were members of the cartel, who set out to dominate the worldwide market for lamp bulbs by nominating agreed production quotas for each manufacturing member in its assigned territory.

Competition from non-member companies soon put paid to the cartel's dreams of world domination. Krajewski reported that, 'As the cartel continued its policy of artificially elevated prices, competitors spotted a golden opportunity to sell cheaper, if often inferior-quality, goods. Particularly threatening was the flood of inexpensive bulbs from Japan.' In the end, the chaos caused by the approach of war made it impossible for the cartel to continue and it was dissolved in 1939. However, its work was not in vain. Although it was perfectly possible to make a lamp bulb that could burn for 2500 hours, the cartel decided that their members' bulbs should last only 1000 hours, which was hardly in the interest of consumers and a strategy that today we could call planned obsolescence.

New life for Li-Fi?

Back in 2013, the technical press was abuzz with reports on 'Li-Fi' – an electro-optical version of Wi-Fi. Prof Martin Dawson, Director of Research in the University of Strathclyde's Institute of Photonics, confidently declared: 'This is technology that could start to touch every aspect of human life within a decade. Imagine an LED array beside a motorway helping to light the road, displaying the latest traffic updates and transmitting Internet information wirelessly to passengers' laptops, netbooks and smartphones. This is the kind of extraordinary, energy-saving parallelism that we believe our pioneering technology could deliver.'

Well, yes. To be fair, there's still a year left, so Li-Fi could still fulfil this prediction – just. And to remind you, Li-Fi is not just optical Wi-Fi but comes with higher capacity and fewer technical hang-ups. However, a clever notion needs a killer application to become a winner, and ten years ago, Li-Fi was very much a solution looking for a problem. Now (or soon) its time may finally have come.

Lightbulb moment

Cast your mind to the burgeoning number of autonomous (self-driving) cars and other road vehicles. Then

consider the vital need for dependable collision-avoidance mechanisms, many of which rely on 100%-reliable, split-second vehicle-to-vehicle (V2V) communication. What a no-brainer – isn't this exactly what radio is for?

Think again; we're talking about safety-critical situations for which you need acutely low-latency and no risk of signal corruption. Optical communication is far more secure, says Mike Sandyck, product marketing manager with international semiconductor manufacturer Onsemi. 'Brake lights could be modulated to let the vehicle behind know that the brakes have been operated – this would be instant, but with RF a delay could be disastrous. RF is easily intercepted, while the localised nature of light adds to security.'

He continues: 'Modulating the light intensity or frequency of LED-based lighting allows data to be transmitted in much the same way as an RF carrier wave is modulated. This opens up applications including light-based Wi-Fi style networking [Li-Fi] and underwater usage. The ability to transmit data via light requires little if any power over and above what is needed for the LEDs and installation costs are low because, in many cases, the lighting is already in place. While the flickering of the lights can be easily detected by a receiver, the frequencies used are imperceptible to humans due to their persistence of vision, so there is no user impact with this technology.'

Looks like we got us a convoy

Truck manufacturer Scania's future vision of Europe's freight transport is of sleek convoys or 'platoons' of trucks travelling autonomously and synchronously along green corridors of 'smart' roads. Says the company's senior business analyst Fredrik Callenryd, 'We would see autonomous trucks travelling in road trains in the foreseeable future, with drivers navigating only when they leave these green corridors, to travel to the depot, for example.' If he is right, V2V communication will be the key enabler and Li-Fi could be the killer app!

Win a Microchip SAM E54 Curiosity Ultra Development Board

Practical Electronics is offering its readers the chance to win a Microchip SAM E54 Curiosity Ultra Development Board (DM320210) – and even if you don't win, receive a 15%-off voucher, plus free shipping for one of these products.

The SAM E54 Curiosity Ultra Development Board includes an integrated programmer and debugger, so no additional hardware is required to get started. Users can expand functionality through MikroElektronika mikroBUS Click adapter boards, add Ethernet connectivity with the Microchip PHY Daughter Board, add Wi-Fi connectivity capability using the Microchip expansions boards, and add audio input and output capability with Microchip audio daughter boards.

With or without expansion boards, the SAM E54 Curiosity Ultra Development Board provides the freedom to develop for a variety of applications, including Bluetooth Audio, CAN, Graphical User Interface, Internet of Things (IoT), robotics development and proof-of-concept designs.

The SAM E54 high-performance microcontroller series features a 32-bit ARM Cortex-M4 processor with Floating Point Unit (FPU) running up to 120MHz, up to 1MB Dual Panel Flash with ECC, and up to 256KB of SRAM with ECC. It also adds a 10/100 Ethernet MAC and two CAN-FD ports targeted for industrial automation, automotive applications and general-purpose applications requiring wired connectivity. The SAM E54 microcontroller series offers excellent features with class-leading power performance and integrated hardware security.

The development board contains a Microchip Embedded Debugger (EDBG) for on-board debugging. The EDBG is a complex USB device, which is based on the following interfaces:

- Debugger
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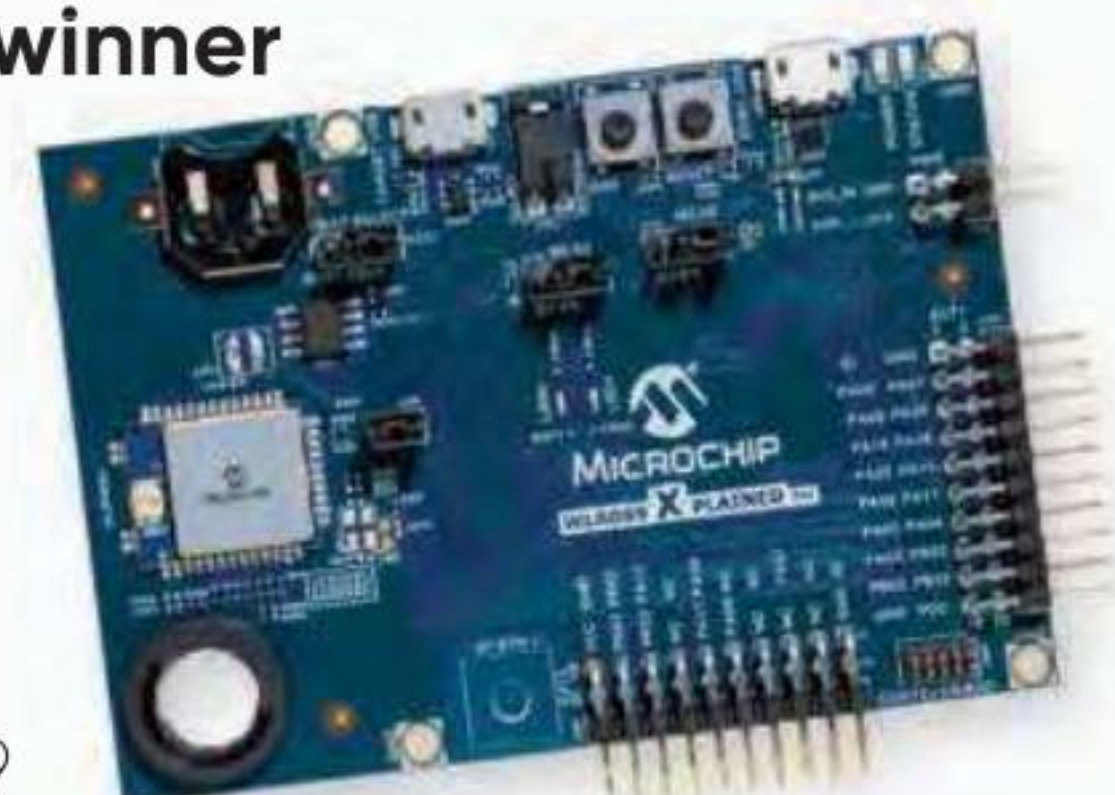
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The Fox Report

Barry Fox's technology column



High drama, but low tech

Covid lockdown has changed the face of cinema by forcing the movie industry to embrace Pay Per View streaming of recent releases. Even though inexpensive HDMI-to-USB equipment is available for use with a PC, along with free open-source software to circumvent copy-protection and 'rip' the material to unprotected MP4 files, there has been no obvious explosion in piracy.

Theatres and music venues have also found new paying audiences by streaming plays and concerts into homes, some for free at the height of the pandemic, but now for hard cash. Although the technology has been maturing, there are still painful reminders that arts folk generally know more about artistic production than selling content online.

I signed up to stream a production by the Young Vic Theatre of the play *Best of Enemies*, a new play (<https://bit.ly/pe-jun22-boe>) by James Graham (author of the TV play *Quiz*, which was about the 'coughing major' who won a million on a TV quiz show).

Best of Enemies dramatises one of the first great TV debates, which took place in the US during the 1968 Presidential campaign between Richard Nixon and Hubert Humphrey. US viewers hugely enjoyed watching opinionated conservative commentator William F Buckley Jr. tangle very publicly with equally opinionated liberal author and arch-enemy Gore Vidal.

Great, but...

Let me say straight off that the *Best of Enemies* play is hugely entertaining and the Young Vic production excellent. The problem was the technical handling and viewer guidance for the 'Best Seat in Your House' streaming system used.

Unlike most home-streamed events, the start time was fixed and there was no option to

re-view later. If a paying customer experienced any technical problems, there was no second chance to watch. This was made clear in advance: 'The performance is being broadcast live, so please join on time – we don't want you to miss anything! The performance will only be available to watch for the duration of the live broadcast' warned the organisers. 'If you have any problems with your broadcast please head to our FAQs page as a first step, and if you can't find what you're looking for, we're always here to help at boxoffice@youngvic.org'. But there was no helpline phone number to call.

Click and join

As recommended by a pre-show instruction email, I 'clicked to join the broadcast' half an hour ahead of time to check the connection. What I then got was a short, recorded loop from a Young Vic artistic guru who obviously already knew the play inside out so also knew how the actors would be moving round the theatre stage – unlike paying customers, who could have no advance idea what they would be seeing.

The artistic gentleman enthusiastically told us that we had a choice of ten camera angles which we could switch between. What only became evident in hindsight was that until viewers had watched the play for a while and got a feel for the direction, they should play safe and choose the last camera option on the list, the 'Directors Cut'; and only experiment with the nine other angles when they felt confident.

Lacking this vital guidance ahead of time I wasted the early part of the play trying to reconcile the different camera angles with the continual, wide-ranging movement of the actors. Viewers should also have been talked through the other confusing options offered, such as Auto Quality and Unpin and Sound On.

Technical faults

During the play, the screen frequently and disconcertingly went briefly black. This was clearly quite different from data buffering and most likely caused by faulty camera switching on one or more of the views. There should have been flashed-up warnings telling people not to try and adjust anything. But there was no guidance.

Feedback

I raised all this with the Young Vic Theatre Management after the event. What I got back, after a reminder, was of little value: 'I'd like to offer my sincerest apologies (etc etc etc) ...about the difficulties you had with the streamed performance of *Best of Enemies*... Your feedback has already been passed on and taken into account for our next shows. As you no doubt know, our venture into streamed performances is a new one to us so any and all feedback is invaluable. I am sorry that you had a bad experience with our tech...Once again, I'd like to apologise for the difficulties you experienced and thank you for your patience with us while we take into account all the feedback available to us in order to make the live streams more streamlined.'

I've heard nothing further. No acknowledgement of the need for better customer guidance, no explanation of or apology for the technical glitches and certainly no chance to view the stream again without glitches and with the benefit of camera angle hindsight.



Early Japanese TV



Japan, May 1930: received picture using Kenjiro Takayanagi's pioneering TV system.

Who invented television? Opinions differ, largely depending on the country where the question is asked and the company answering it. But the basics are generally agreed. In 1884 German Paul Nipkow proposed a spinning disc with a spiral track of holes that let light through to a photo sensor, to scan an image.

In the mid-1920s, Charles Francis Jenkins in the US and John Logie Baird in the UK tried to turn the Nipkow disc into a working TV system. Baird got further with the idea than Jenkins, but TV based on mechanical moving parts was always going to fail in the end.

Starting in 1927, US inventor Philo Farnsworth patented an all-electronic scanning system. Russian emigree David Sarnoff and the Radio Corporation of America threw money at the idea and made it work – with the help of another Russian emigree, Vladimir Zworykin. Sarnoff bullied Farnsworth out of his patent rights – just as he would later do to Edwin Armstrong, inventor of FM radio.

In April 1927 AT&T Bell Telephone Labs made headline news by sending all-electronic pictures by copper wire from Washington to New York.

In the mid-1930s, Telefunken in Germany and EMI in the UK took the development of all-electronic television to new levels, with systems that used over 400 scanning lines and were then thought of as 'high definition'.

There is seldom any mention of Japan's role in early television, but JVC, the Japan Victor Company, will tell you that Kenjiro Takayanagi (1899-1990) played a major and largely sidelined

part in bringing television to the masses. And buried in JVC's vaults there are pictures to prove it.

Takayanagi started out as a teacher, then worked for the Japan Broadcasting Company and joined the Victor Company where he rose to the role of vice president. He used a mechanical Nipkow disk and a photoelectric tube in the transmitter, but electronic Braun cathode ray tube in the receiver.

His first transmission, which used 40 scanning lines, was on 25 December 1926. In 1928 he sent and received an image of a person, again with 40 scanning lines at 14 frames/second.

Takayanagi built an electronic television camera in 1933, shortly after Vladimir Zworykin in the US, and went on to make a 100-scanning-line, 20-frames-per-second system.

More technology stories and images at: <https://tekkiepix.com/stories>

Practical Electronics is delighted to be able to help promote Barry Fox's project to preserve the visual history of pre-Internet electronics.

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Teach-In 9 – Get Testing!

This series of articles provides a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. It provides hints and tips on using, and – just as importantly – interpreting the results that you get. The series deals with familiar test gear as well as equipment designed for more specialised applications.

The articles have been designed to have the broadest possible appeal and are applicable to all branches of electronics. The series crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the most sophisticated microcontroller system. There really is something for everyone!

Each part includes a simple but useful practical test gear project that will build into a handy gadget that will either extend the features, ranges and usability of an existing item of test equipment or that will serve as a stand-alone instrument. We've kept the cost of these projects as low as possible, and most of them can be built for less than £10 (including components, enclosure and circuit board).

PLUS! You will receive the software for the *PIC n' Mix* series of articles and the full *Teach-In 2* book – *Using PIC Microcontrollers – A practical introduction* – in PDF format. Also included are Microchip's *MPLAB ICD 4 In-Circuit Debugger User's Guide*; *MPLAB PICkit 4 In-Circuit Debugger Quick Start Guide*; and *MPLAB PICkit4 Debugger User's Guide*.



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Net Work

Alan Winstanley

Our column of technical trends tries the worthy Google Lens app, highlights the good work of Unilever in helping youngsters manage their online self-esteem, plus we have the latest energy and space news.

A friend from overseas sent me a photo by WhatsApp of a striking yellow flowering shrub that was blossoming in their Mediterranean garden. She asked me if I knew what it was. One way of finding the specimen's botanical name might be to trawl through search engines before hitting some web pages dedicated to 'yellow Mediterranean flowers' and comparing them. Although I found some similar matches, the results were inconsistent: the flower could be anything, I mused, and the mysterious Mediterranean shrub defied recognition!

A smarter way of finding the answer would be to use Google Lens. This underrated and underused app couples

a smartphone to Google's AI and turns it into a highly capable image recognition and translation device. It can scan images stored in a smartphone's gallery or it can use the phone's camera, in which case the app's surprising capabilities come to the fore.

As a simple example, googling for 'Mona Lisa' turns up 1.2 billion search results, but what if you've got a picture of Da Vinci's masterpiece instead, and want to know more about it? Google Lens will capture the image and search for near-enough matches in its database before returning with search results to click through. I opened Google Lens and navigated to the WhatsApp image of the yellow flower stored in the phone's memory. The screen's curved corner icons can crop the recognition area if needed. Choosing the Search function from the app's horizontal sliding menu, Google Lens 'reads' the image and returns any likely matches. Back came an answer: the shrub was clearly a Yellow Flax (*Reinwardtia indica*)! It matched perfectly. Impressed with my supposed expertise, my gardening friend then sent a photo of a mystery bug on an outdoor shrub, which Google Lens identified as a scale insect. From

there, we could find advice for dealing with the infestation. The app can't be expected to always give accurate answers, and having a good quality, high contrast image can only help.

The app has more surprises up its sleeve, especially when using the camera to capture images. It will scan Quick Response / QR codes and offer to open a website URL, or the app can try to recognise and answer written 'Homework Questions' or phrases. Remembering that Google also has an exceptional language translator, by linking it with Google Lens the result is a remarkable device that you can aim at foreign text, and a good-enough translation will appear in virtual real time on the camera screen. It has to be seen to be believed.

A recent practical application related to an electronic ballast that I'd bought for a fluorescent tube repair. Its cardboard carton bore Chinese text, so out of interest, I fired up Google Lens and hit the 'Search with your camera' icon before pointing the camera at the box. After selecting the 'Translate' menu function, the app automatically detected Simplified Chinese and translated it into English, confirming that the ballast has 'abnormal protection function' and is 'suitable for T5/T6 fluorescent tubes' (in case you've ever wondered, the 'T' number is a fluorescent tube's diameter in eighths of an inch). There's more: Google Lens's text-to-speech recognition can also read out the results in plain English: using the 'Text' menu option, the app read the Chinese text out loud as well, much to my mirth. Simply choose 'Listen' from the Text sub-menu.

It can be great fun to try Google Lens with, for example, wildflowers or photos of landmarks, or translating foreign print. More details are at: <https://lens.google/> and the free app can be downloaded for Android or Apple devices from your usual online store. In theory, it's also possible to use Google Lens on a desktop PC using an Android emulator, something for power users to try.



Google's Lens app uses a smartphone camera to identify a work of art in a snap.



The mysterious Mediterranean flower, recognised as *Yellow Flax* by Google Lens.

An anti-virus dilemma

The turmoil unfolding in Eastern Europe is rippling through to the anti-virus software sector, with Kaspersky rapidly falling out of favour in some quarters; its anti-virus protection was banned from US Government departments five years ago, and the firm has now become the first Russian company to be banned by the FCC on the grounds of the potential threats it poses to American national security. Kaspersky claims that America's move is entirely political, and the firm has no connection with Russian Government security services. Germany's Information Security Office (BSI) has also warned all users to analyse the risks and consider de-installing Kaspersky products.

The privately owned Moscow-based company's anti-virus products are well specified and very highly regarded, frequently receiving top ratings for safeguarding personal computers against malware or unsafe e-commerce links. In fact, the author uses Kaspersky on several PCs. The product has a few idiosyncrasies, and it can be a handful to configure and tweak into operation, but it is constantly updated

and provides robust protection for PC or mobile users.

We've been in this dilemma before, when Chinese smartphone maker Huawei was added to the US Entity List, to stop Huawei from becoming embedded into national telecoms networks. Mindful of the 5G roll out, Britain too – eventually – started the lengthy process of ripping out Huawei telecoms equipment from its infrastructure. Later generation Huawei phones have been banned from accessing Google's online services, but the author still uses his excellent (pre-Trump ban) Huawei smartphone; it updates itself regularly enough, but for all I know it could be relaying all my drivel directly to Beijing, or installing spyware in my online banking app. Likewise, I have no reason to think that Kaspersky anti-virus updates are infiltrating my network, but the fear and uncertainty sewn means that ordinary consumers and small businesses now face the choice of either accepting any supposed risk or swapping to another product.

Shrinking choices

Anti-virus software choices are becoming fewer all the time. Alternative products include AVG, which has been acquired by Avast (www.avast.com), both brands hailing from the Czech Republic. Symantec AntiVirus originated out of Norton's products, resulting in some messy and confusing co-branding down the years. Symantec is now NortonLifeLock (www.nortonlifelock.com), a conglomerate that is now attempting to acquire Avast as well. As at mid-March, this £6bn merger had been called in by Britain's Competition and Markets Authority (CMA) for an in-depth investigation, as the takeover deal may reduce consumer choice. In 2021, the CMA took what it called unprecedented legal action against NortonLifeLock, after Norton refused to comply with the authority's demands for information regarding automatic renewals of anti-virus software. Following CMA intervention, both Norton and McAfee undertook to make the auto-renewal option more transparent and easier to opt out.

When I last covered Kaspersky, I mentioned how the product could be bought, downloaded and activated automatically using an Amazon user's Software Library: the system was extremely slick and worked perfectly. As alternatives, at the time of writing, Amazon is offering Norton 360 Deluxe 2022 for 5 Devices, a one-year licence with automatic renewal for just £9.99 ('save £70.00 on RRP'), though, as we all know, RRP's are meaningless. A

postal-activation version is also available for £10.99.

Norton's sales patter claims that users will, 'Enjoy peace of mind knowing that their subscription will not lapse' while the product box-shot clearly states that users 'get an Email reminder before renewal' and that you can 'cancel subscription renewals at any time' – if you can remember. Check Amazon for more details of the download version.

What about alternatives? Founded in Romania, rival Bitdefender offers Total Security 2022 for 5 Devices, with a one-year Subscription for £19.99 via Amazon, with activation by post. There's also F-Secure Total from Finland, costing £59.99 via Amazon, or the well-regarded TotalAV from UK-based Protected.Net, which was on promotion for £39 from www.totalav.com/ultra-deal when I checked.

In every case, be sure to download either from (say) Amazon or from the vendor's own website. Beware of clicking through to fake websites, especially when googling around for brand names or sources. Also watch out for those automatic second-year renewals, which could cost substantially more than an introductory offer.

Dove shapes a youngster's self-esteem

Like many *PE* readers, I grew up with the Internet in the days of the DOS prompt and floppy disks, when something called the 'information superhighway' was still evolving and the world-wide web barely existed. Getting online was pretty difficult, slow and expensive, and the cost and complexities of PC ownership, sending an email or creating a web page meant the Internet was far beyond the reach of the mass market. Gradually, the Internet morphed into today's medium that brings us streaming content, social media, online shopping, appliance control and everything else that we use all day, every day.

The accessibility of the web, especially for younger people, means that it's now totally effortless to post quick videos or photos on Tik Tok or YouTube, or share them with friends on Facebook, or message people with WhatsApp, and so on. There's now a whole generation that has never known life without the Internet, which has brought with it a whole new range of social malaise. Impressionable young people may neither be equipped nor discerning enough to handle the pressure brought to bear by streaming content, 'news' sites or social media, and exposure to the relentless onslaught of web content can affect the ability of young minds to process it safely.



The app's text recognition and language translation are impressive. Here, Simple Chinese text on a carton is translated into plain English in near real-time.

A recent Ofcom study in the UK revealed that a third of online users don't know whether online content is true or fake, and 6% believe that everything they see online is true. (See more guidance at <https://sharechecklist.gov.uk>) The Ofcom survey also highlighted the worrying trend of youngsters (dubbed 'Tik Tots') using social media sites, even if they were below the permitted age of 13.

In some cases, a relentless diet of celebrity glamour, social media and peer pressure can damage a young person's self-esteem, which is why Unilever's Dove toiletries brand is offering online resources to support parents and teachers who may be confronted by younger people, predominantly girls, suffering from low confidence or self-worth. The Dove Self-Esteem Project found that 85% of 509 girls aged 13-17 who used social media in the UK agreed that they either downloaded a [graphics] filter or used an app to enhance their identity. The Dove project at Dove.com/confidence offers some very worthwhile free downloads for parents and teachers, including *The Confidence Kit*, a 32-page guide for parents that helps youngsters develop their own self-confidence and hopefully dissuade them from wanting to glamorise their looks online.

Parents of younger children might in any case want to read the Ofcom report and advice at: <https://bit.ly/pe-jun22-ofc>

Colour-coded energy

On the energy front, the UK Government is rapid-firing announcements about its 'green energy' plans which could

see Britain's elderly generation of nuclear reactors replaced with up to eight new ones, a lofty ambition that would take until the middle of the century to materialise. The new 'Hinkley Point C' nuclear power station, started in 2018 and slated for completion by 2026, is the first to be built in twenty years (<https://bit.ly/pe-jun22-hpc>) and a second one in the pipeline – Sizewell C – will likely take at least ten years to complete (see <https://bit.ly/pe-jun22-szc>). Britain's nuclear power and shale gas extraction plans have a troubled history of short-sighted policymaking decisions, but the country is now betting the ranch on renewable energy, including more solar power and offshore fixed and floating wind turbines, while at the same time weaning the country off imported natural gas.

Regular *Net Work* readers will know how small modular nuclear reactors (SMRs) have been floated as the fast-track solution for bringing more nuclear power on stream. SMRs can be built in factories, with sections transported by road for final assembly on site. Rolls-Royce explains its own SMRs in an interesting video at <https://bit.ly/pe-jun22-rr>

The idea of SMRs is not unique to Rolls-Royce though, and a number of US rivals are jostling to get on board. Deliveries of the first SMRs are probably at least eight years away, leaving consumers and industry facing energy uncertainty in the short to medium term. A rival US manufacturer, Last Energy (www.lastenergy.com), is reportedly offering to pilot an SMR in the UK by 2025, aiming to have ten of them running by 2030. They also expect to build a 20MW pilot plant in Romania. America's NuScale is also scoping out the UK and Eastern Europe (see *Net Work*, February 2022).

The production of hydrogen, the ultimate clean fuel but energy-intensive to manufacture, is also on the radar. As *Balkan Energy News* helpfully explains (<https://tinyurl.com/ydvf3tj8>), 'Last Energy suggests its mini nuclear plants could be sited next to energy-intensive facilities to reduce costs of infrastructure and transmission. The heat and electricity from an SMR can also be used to produce hydrogen via water electrolysis... When the process is powered by nuclear energy, it is called pink hydrogen. It is green hydrogen if electricity from renewables is used. Grey hydrogen is produced from gas, but it is called blue hydrogen if carbon dioxide emissions are captured and then stored or used for a different industrial purpose.'

An entire spectrum has evolved to denote hydrogen's origins, including turquoise, yellow, brown and white hydrogen – the colour code is listed by National Grid at: <https://tinyurl.com/y2twexb8>

In a decade's time we can expect to see SMRs popping up all over the place, except in Scotland: the country's largely separatist government intends to veto the building of any nuclear power stations there. Ironically, the UK could become a net exporter of energy to the EU, the economic bloc that includes France which last year threatened to cut off electricity to the Crown Dependency island of Jersey off the coast of France (<https://bit.ly/pe-jun22-je>), because of a UK-France fisheries dispute.

Space stations

All eyes are on the NASA Artemis moon mega rocket, the monster truck of space travel, as it's gradually readied for its first test flight from Kennedy Space Center a few months from now. March saw the arrival of the giant Artemis SLS (Space Launch System) rocket and Orion crew capsule in preparation for a 'wet dress rehearsal', the last major test of a system's integrity before an uncrewed launch later this year. Space fans can follow it at: www.nasa.gov/artemis-1

On a neighbouring launchpad, Axiom Space's Ax-1 mission successfully launched an all-private crew to the



NASA's Space Launch System (SLS) and Orion capsule conducts a 'wet dress rehearsal' test at the Kennedy Space Center in Florida.
Photo Credit: (NASA/Joel Kowsky)



Axiom Station will be the first commercial space station; assembly starts in 2024.

international space station on a SpaceX Falcon 9 on 8th April. Axiom Space aims to construct Axiom Station, the world's first commercial space station in coming years and naturally I hope to report on progress in future columns. See www.axiomspace.com for news.

In the satellite broadband sector, SpaceX continues to launch more Starlink satellites into a LEO (low earth orbit) and, as a nice gesture, has offered to partner with smaller rival OneWeb whose Soyuz-based launches from Kazakhstan were collateral damage of the Ukraine crisis (see last month). The UK-based LEO operator is attracting a lot of interest and is backed by a farsighted UK Government and India's Bharti Global, with Eutelsat now taking a 23% share. Other investors include South Korea's Hanwha, Hughes Network Systems and Japan's Softbank.

Amazon's satellite broadband program – Project Kuiper – has been late to the table, but its launch schedule is now taking shape. Reports suggest that, compared with Starlink, Project Kuiper will use heavy lifter rockets to place larger numbers of satellites into orbit at a time, meaning fewer launches would be needed. Amazon is spreading its bets and initial deals have been inked with Blue Origin (owned by Jeff Bezos – see the March 2020 *Net Work*), Arianespace (18 launches over three years, the largest in its history) and 38 launches with United Launch Alliance (Lockheed Martin / Boeing). Amazon says the contracts cover up to 83 launches over five years, building capacity for Amazon to deploy most of its proposed 3,236-satellite constellation. It is the largest commercial

procurement of launch vehicles in history, they add.

Last this month, the Fisker Ocean electric SUV mentioned in May's *Net Work* received 40,000 reservations and Fisker is opening pre-orders for a limited-edition Fisker Ocean One in July due to anticipated demand, the company says. They added that many reservation holders intend to purchase the Ocean One launch edition or Ocean Extreme models, both priced at £59,900 in the UK. Visit www.fiskerinc.com for more information on the forthcoming model. The spiralling asking prices for EVs might see drivers simply leasing them instead (or 'subscribing' as Volvo now calls it).

See you next month for more *Net Work*!

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Full-wave Universal Motor Speed Controller

Want exceptionally smooth speed control over the entire range for your power tool? You want our new *Full-wave Universal Motor Speed Controller*. It is ideal for use with mains-powered electric drills, lawn edgers, strimmer / whipper snippers, circular saws, routers or any other appliance with universal (ie, brush-type) motors, rated up to 10A.

By **JOHN CLARKE**

Our latest **Full-wave Universal Motor Speed Controller** is an upgrade on the one we published in July 2019. That one worked very well, but we identified several upgrades and improved features that could be made to the design.

One of the main drawbacks of the previous design was that the feedback gain control was located inside the *Controller's* housing. That control set the amount of compensation for maintaining motor speed under load.

Once set, the *Controller* was only suitable for the appliance being used, since the feedback control would require changing for different motors.

This control is now externally adjustable via a control knob, making it easy to use the *Controller* across a range of different power tools and other devices.

We have also added the ability to switch the soft-start feature off, also via an external switch. Soft start is useful when the *Speed Controller* is set at a certain speed and the motor is switched on and off at the appliance. When the

appliance is switched on, the motor speed is slowly and automatically brought up to the set speed. Without it, power to the motor is suddenly applied, and the motor can kick back.

Soft start is essential when using the *Controller* with a high-powered router or circular saw. For smaller appliances, and when the motor is switched on and off often, you might find that it limits how fast you can work, as you wait for the motor to come up to speed.

That would be the case when used with a strimmer / whipper snipper and some hand drills. So we made it so you can easily switch the soft start feature off. While we were making those changes, we took the opportunity to improve its ability

to maintain motor speed under load, especially at low speed settings and for low-power appliances.

The *Full-wave Universal Motor Speed Controller* can be used with mains supplies over the range of 220-250V AC at 50Hz or 60Hz. This means that it can be used in many different countries, **although it is not suitable for use with 100-120V AC mains supplies.**

WARNING!

This Speed Controller operates directly from the 230V AC mains supply and contact with any live component is potentially lethal.

Do not build it unless you know what you are doing.

DO NOT TOUCH ANY PART OF THE CIRCUIT WHILE IT IS PLUGGED INTO A MAINS OUTLET and never operate it outside its earthed metal case or without the lid attached.

This circuit is *not suitable* for use with induction motors and must only be used with universal 'brush type' (series-wound) motors or shaded pole (fan) motors with nameplate ratings up to 10A. For more information, see the section titled 'What motors can be controlled'. Power tools with inbuilt fans must not be operated at low speeds for extended periods; otherwise, they could overheat.

The *Controller* is mounted in a relatively low-profile diecast aluminium case with mains plug and socket leads attached to one end, through cable glands. A panel fuse is also provided on the same end of the case.

The speed control and feedback gain potentiometers, and soft start switch are mounted on the lid.

Why do you need speed control?

Most power tools will do a better job if they have speed control. For example, electric drills should be slowed down when using larger drill bits as they make a cleaner cut. Similarly, it is useful to be able to slow down routers, jigsaws and even circular saws when cutting some materials, particularly plastics, as many will melt rather than be cut if the speed is too high. The same comments apply to sanding and polishing tools, and even electric lawn trimmers; they are less likely to snap their lines when slowed down.

What motors can be controlled?

This *Controller* suits the vast majority of power tools and appliances. These generally use universal motors which are series-wound motors with brushes. They're called universal motors because they can operate on both AC and DC.

You cannot control the speed of any universal motor which already has an electronic speed control built in, whether part of the trigger mechanism or with a separate speed dial.

That does not include tools such as electric drills which have a two-position **mechanical** speed switch. In that case, you can use our *Speed Controller* with the mechanical switch set to fast or slow. The slow selection usually drives the motor with a half-wave voltage.

Induction motors (except shaded-pole types, which are often found in fans and such) must not be used with this *Speed Controller*. How do you make sure that your power tool or appliance is a universal motor and not an induction motor? One clue is that most universal motors are quite noisy compared to induction motors. However, this is only a guide, and it's certainly not foolproof.

In many power tools, you can see that the motor has brushes and a commutator (usually through the cooling vents) and you can see sparks from the brushes during operation. That indicates that the motor is a universal type. But if you can't see the brushes, you can also get a clue from the nameplate or the instruction booklet.

Most induction motors used in domestic appliances will be 2-pole or 4-pole types which operate at a fixed speed,

Features

- ★ For universal and shaded-pole motors rated up to 10A
- ★ Runs from 220-250V AC at 50Hz or 60Hz
- ★ Full-wave motor speed control
- ★ Full speed range (from nearly zero to close to 100%)
- ★ Current feedback for maintaining speed under load
- ★ Feedback gain adjustment
- ★ Optional soft start from zero speed and at power-up
- ★ Optimised control for inductive loads such as motors

typically 2850 RPM for a 2-pole unit or 1440 RPM for a 4-pole unit. The speed will be on the nameplate. Bench grinders typically use two-pole induction motors.

If you do need to control the speed of this type of motor, use the *1.5kW Induction Motor Controller* published in January and February 2019.

Phase control

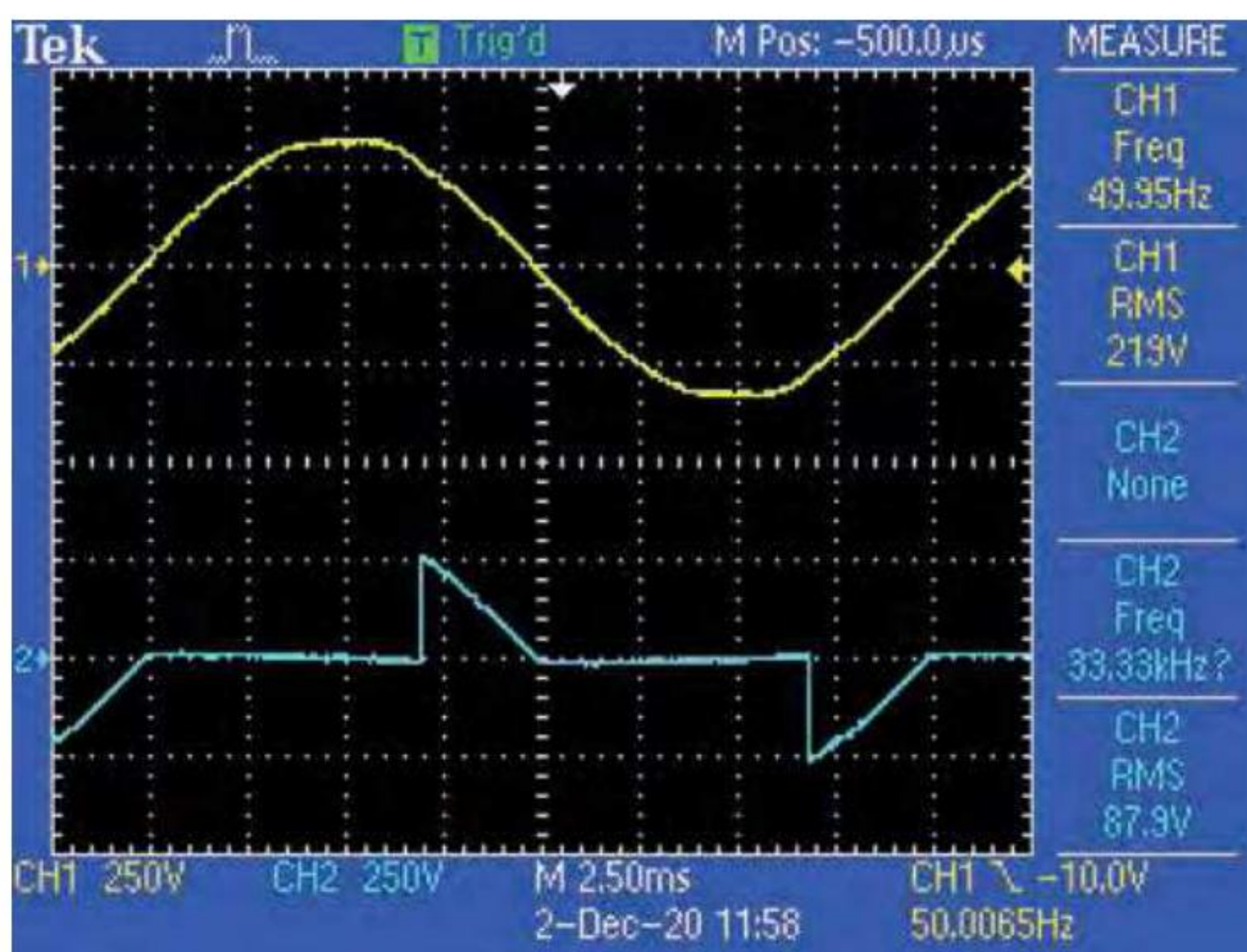
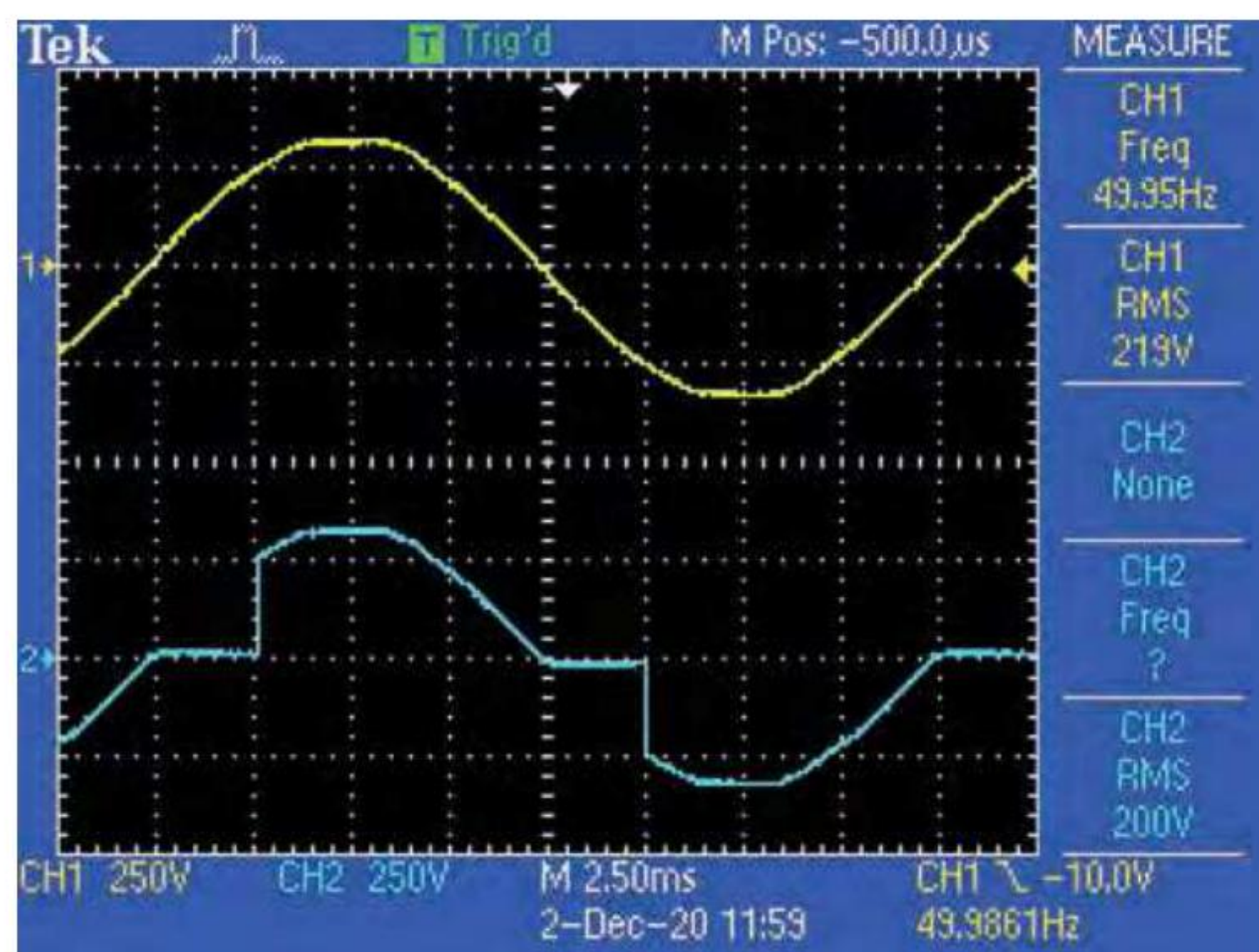
The AC mains voltage closely follows a sinewave. It starts at 0V, rises to a peak, falls back to 0V, then does the same thing in the opposite direction. This repeats 50 times per second for 50Hz mains, or 60 times per second for 60Hz mains.

A motor connected to the mains makes full use of the energy from each cycle so that it runs at its maximum speed. So, if supplied only a portion of this sinewave to the motor, with less energy available to power it, the motor would not run so fast.

Varying the time during each half-cycle when voltage is applied to the motor gives speed control. This is the basis of phase control: start feeding power very early in the cycle, and the motor runs fast; delay power until much later in the cycle, and it runs more slowly.

The term 'phase control' comes about because the timing of the trigger pulses is varied with respect to the phase of the mains sinewave. Several devices can be used to switch the mains voltage; here, we are using a Triac. That device can be used to switch both the positive and negative voltage excursions of the mains waveform.

The oscilloscope traces show phase control varying the power to an incandescent light bulb, as this shows phase control in its pure form, without the extra hash caused by driving a motor.



Specifications

- ★ Power: 230V AC sinewave up to 10A
- ★ Operating frequency: any fixed frequency between 40Hz and 70Hz
- ★ Soft start rate: two seconds from start to full speed
- ★ Triac gate drive: 68mA
- ★ Triac gate pulses, phase angle $< 90^\circ$:
40 μ s gate pulses repeated at 200 μ s intervals

Scope1 shows the chopped waveform from the phase control circuit when the incandescent light bulb is driven at high brightness. This is equivalent to driving a motor at a fast speed. Here, the Triac is triggered 2.5ms after the zero-crossing (the point where the mains waveform passes through 0V).

The voltage applied to the load is the cyan trace, and measures 200V RMS. That is less than the 219V RMS mains waveform shown by the yellow trace.

Scope2 shows the waveform from the phase controller driving a light bulb at a lower setting, with the Triac triggered later in the cycle. The voltage applied to the load is now much less at 87.9V RMS.

Scope3 shows the waveform when driving a motor. The lower blue trace is the voltage applied to the motor, with the input mains shown on the top (yellow) trace. Note the extra hash on the lower trace due to the motor being an inductive load.

Speed control

For a motor to have good low-speed performance, the *Controller* needs to compensate for any drop in motor speed as the load increases. Many phase-based speed controllers rely upon the fact that a motor can be used as a generator when it is spinning with no power applied. When the motor is loaded and the motor speed slows, the back-EMF (electromotive force) produced by the motor drops, and the circuit compensates by providing more of the mains voltage cycle to the motor, triggering the Triac earlier in the mains cycle.

However, in practice, the back EMF generated by most series motors while the Triac is not conducting is either very low or non-existent. This is partly because there is no field current, and the generation of voltage is only due to remnant magnetism in the motor core. If there is any back-EMF produced, it is too late after the end of each half-cycle to have a worthwhile effect on the circuit triggering in the next half-cycle.

So we use a different method for speed regulation, by monitoring the current through the motor. When a motor is unloaded, it draws a certain amount of current to keep itself running.

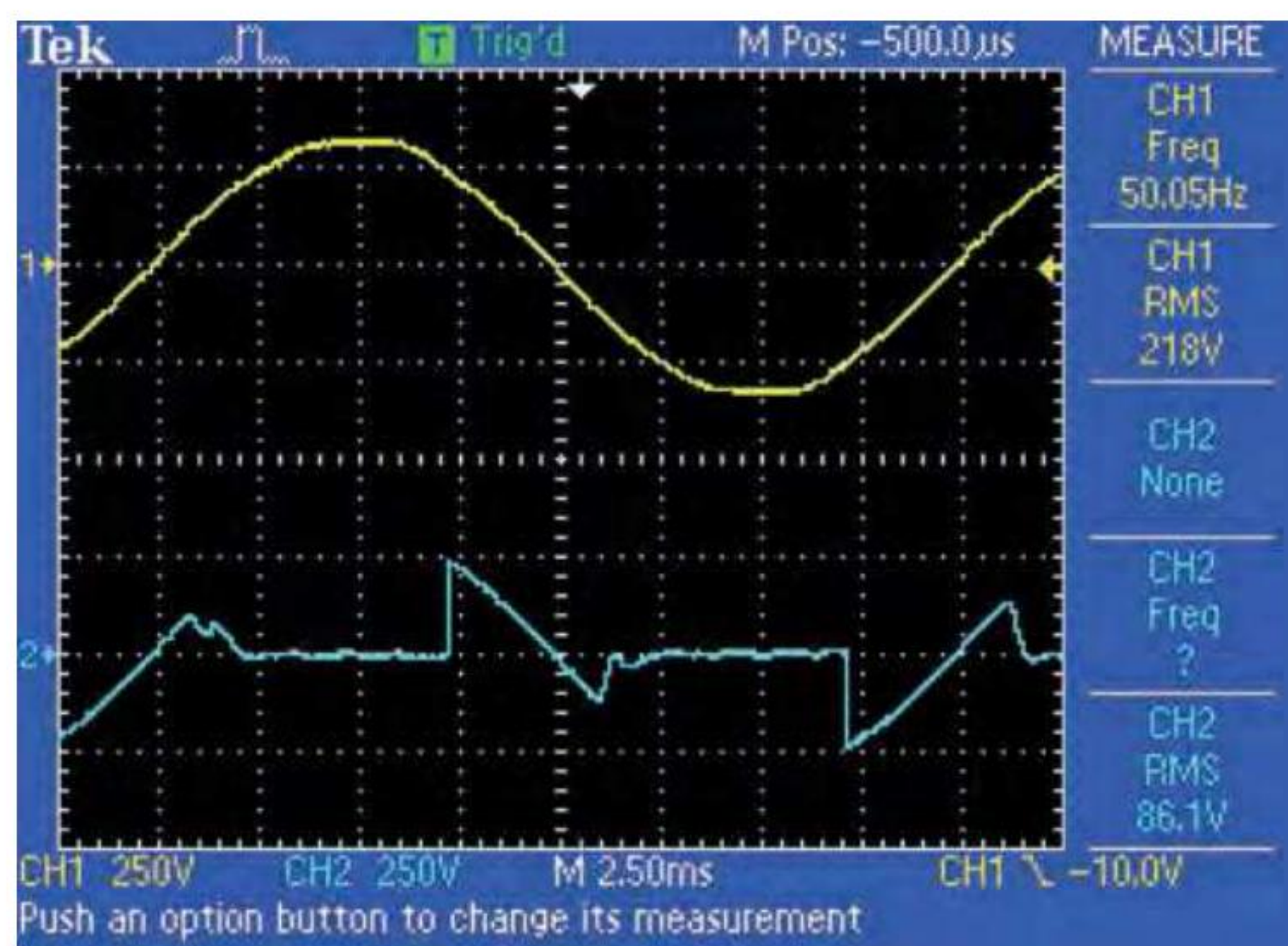
When the motor is loaded, the motor speed drops and the current draw increases. The motor controller senses this, and compensates for this speed drop by increasing the voltage to the motor.

This might sound like positive feedback, where the detection of more current drawn will increase the voltage and so allow the motor to draw more current. It's true that this can happen if the amount of compensation is too high, which is why we include a feedback control knob, to adjust the compensation gain.

With the right setting, the speed regulation is very impressive, but too much feedback will have the motor increasing in speed with increased load instead of maintaining the set speed.

Controlling a Triac with an inductive load

One major problem when using a Triac for full-wave control of a motor is the way a Triac switches off and the nature of



Scope3: the same speed setting as shown in Scope2, but this time with a motor attached. The inductance of the motor windings causes the Triac to switch off after the zero-crossing due to the output current phase shift from its reactance.

the motor load. A Triac is usually switched on by applying a current to its gate. If the current flowing between the Triac's main terminals is greater than its holding current, the Triac will remain switched on for the remainder of the mains cycle.

A Triac will only switch off when the gate is not being driven and the Triac current drops below its holding current. Since a motor is not a purely resistive load, but instead has a significant inductance, the motor current lags the voltage. That means a Triac driving a motor will not necessarily switch off at the zero-crossing; motor current can continue to flow for sometime after.

Our circuit uses a microcontroller to produce the required gate pulses to correctly drive an inductive load like a motor using a Triac. It feeds a series of gate pulses to the Triac to provide for the full range of phase control.

Circuit description

The *Speed Controller* circuit is shown in Fig.1. Its key components are Triac Q1 and PIC12F617 microcontroller IC1.

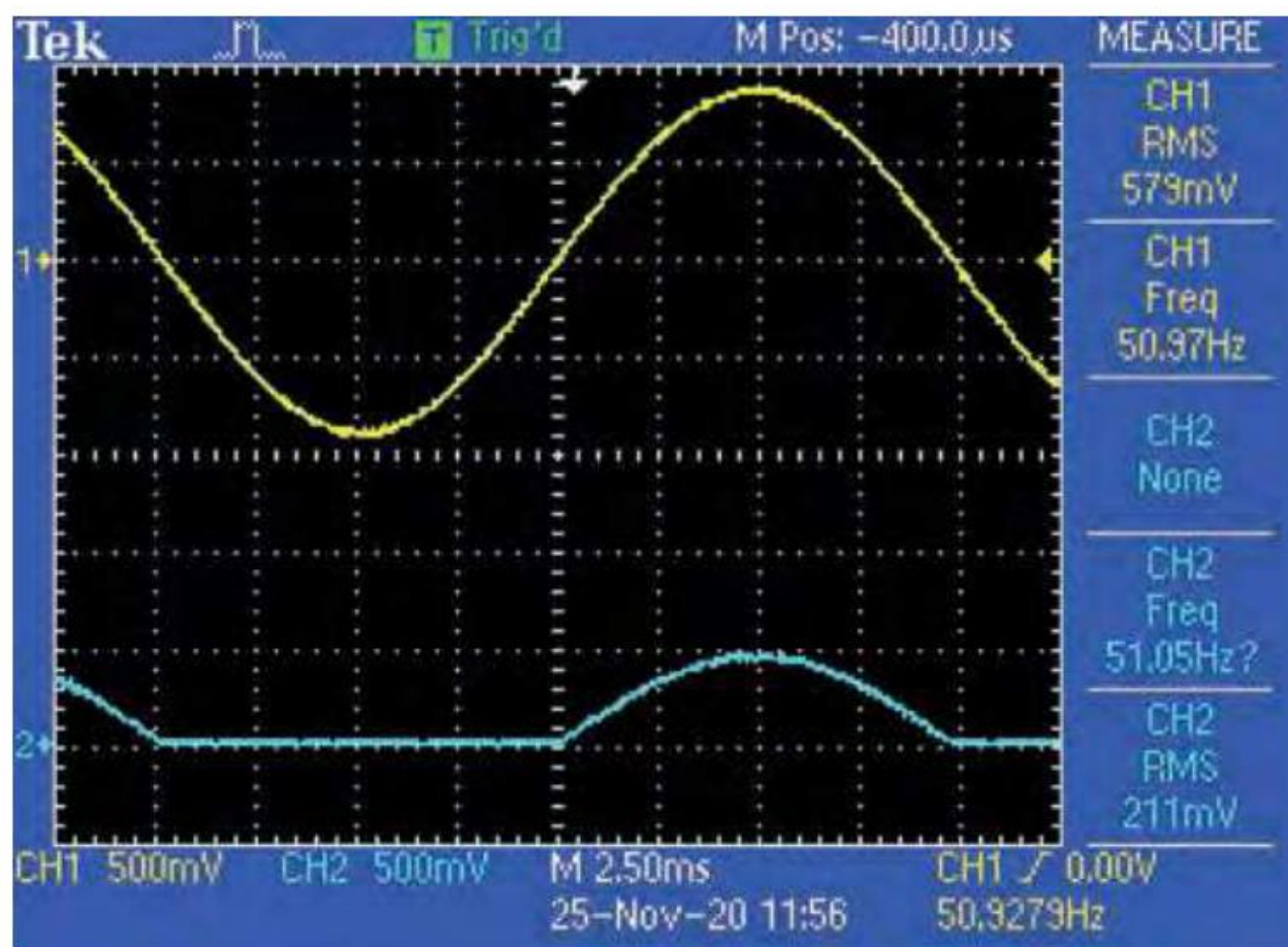
IC1 monitors the speed potentiometer (VR1) at its analogue input AN1 (pin 6) and the feedback gain potentiometer (VR2) at AN0 (pin 7). It also monitors the motor current at analogue input AN3 (pin 3), with that signal originating at current transformer T1 and passing through a full-wave rectifier based around IC2. The mains voltage waveform is monitored for zero crossings at pin 5, via a 330k Ω resistor.

In response to all those parameters, IC1 produces a series of pulses at its digital output GP5 (pin 2), and these drive the base of NPN transistor Q2 which, in turn, sinks current from the gate of Triac Q1. The Triac gate current flows via the 47 Ω resistor connected between the 5.1V supply and the Triac's A1 terminal, then out through the gate and to circuit ground via Q1 (ie, the gate current is negative).

This method of connection places the 47 Ω resistor between the 230V AC mains supply and the 5.1V supply which runs the PIC microcontroller. This avoids Triac switching noise getting into the 5.1V supply, which can cause the microcontroller to latch-up.

Snubber

The snubber network comprises two 220 Ω 1W resistors in series and a 220nF 275V AC X2-rated capacitor connected between the A1 and A2 terminals of the Triac. This network prevents rapid changes in voltage from being applied to Triac Q1, which would otherwise cause it to turn on (due to dV/dt switching) when it is supposed to be off.



Scope4: the first stage of the precision full-wave rectifier works as a half-wave rectifier with an output voltage half that of the input. Both signals (original and clipped/attenuated) are fed into the second stage and combined to produce the output shown in Scope5.

These rapid changes in voltage can occur when power is first applied, or can come from voltage transients generated by the inductance of the motor being controlled each time the Triac turns off. The snubber network acts to damp transients and reduce their amplitude.

The DC supply for the microcontroller is derived directly from the 230V AC mains supply via a 470nF 275VAC X2-rated capacitor in series with a 1kΩ 5W resistor. The capacitor's impedance limits the average current drawn from the mains, while the 1kΩ resistor limits the surge current when power is first applied.

When the neutral line is positive with respect to live, current flows via the 470nF capacitor, diode D1 and 47Ω resistor to the 1000μF capacitor to charge it up. On negative half-cycles, the current through the 470nF capacitor is reversed and flows through diode D2, discharging the capacitor back into the mains.

Zener diode ZD1 limits the voltage across the 1000μF capacitor to 5.1V. This is the supply for microcontroller IC1, op amps IC2a and IC2b, and for the gate current of Triac Q1. IC1's 5.1V supply is bypassed with a 100nF capacitor while IC2 is bypassed with 100μF.

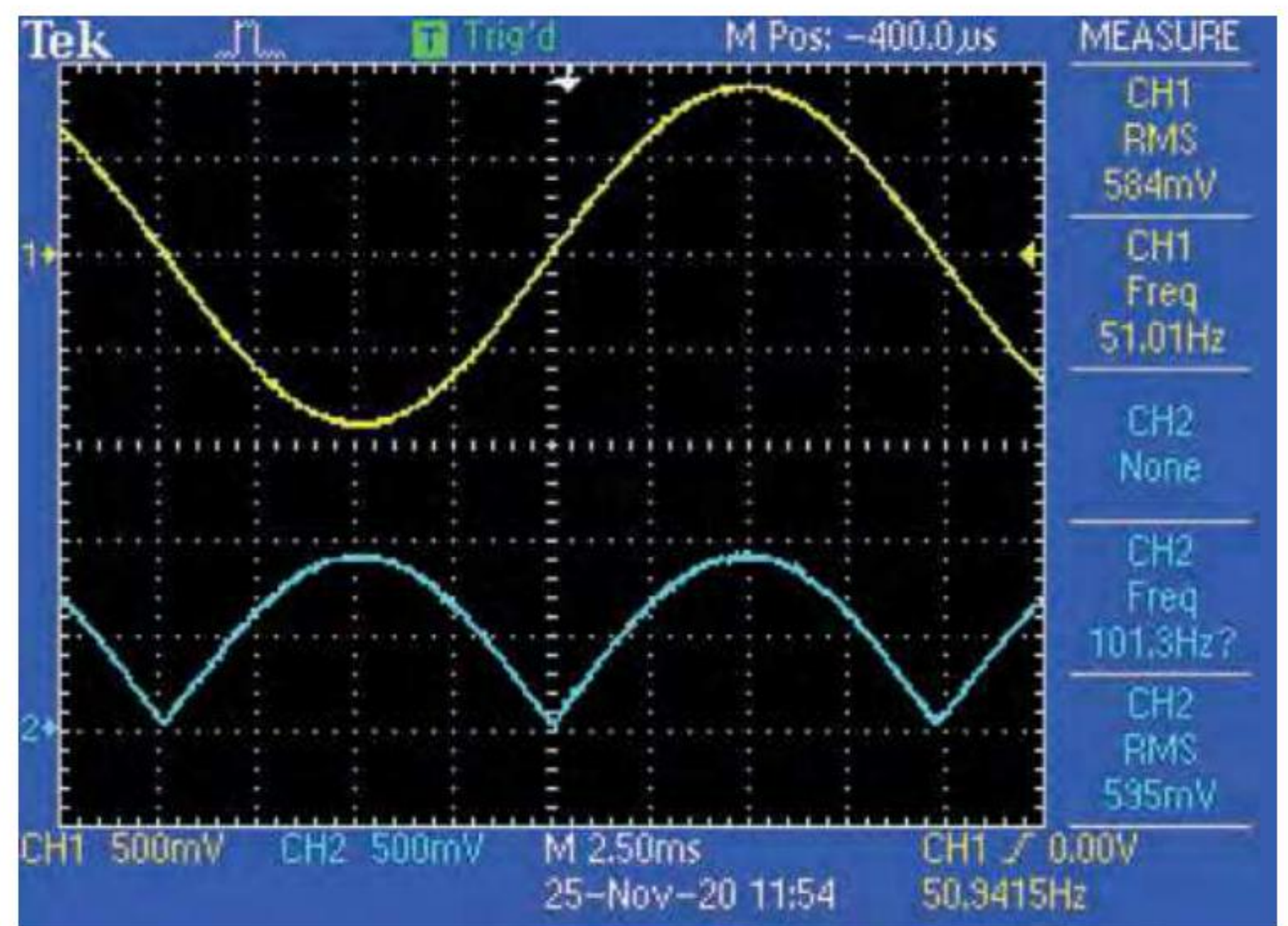
Switch S1 allows the soft-start feature to be enabled or disabled. This switch controls the input level of the GP3 input (pin 4). When S1 is open, the GP3 input is held high at 5.1V via a 47kΩ resistor, so soft start is disabled. When switch S1 is closed, GP3 is pulled low, and the program runs the soft-start routine.

S1 pulls GP3 low via a 100Ω resistor, which is included to protect the input from current transients that could cause latch-up in the IC. The 100nF capacitor provides a low impedance to transients, preventing incorrect detection of the GP3 input when S1 is open due to transients or interference.

VR1 is the speed potentiometer, and it is connected across the 5.1V supply. IC1 converts the voltage from VR1's wiper into a digital value using its internal analogue-to-digital converter (ADC). The 100kΩ resistor from the wiper to ground holds the AN1 input at 0V, setting the motor speed to zero should VR1's wiper go open-circuit.

Potentiometer VR2 is connected similarly. Its wiper voltage sets the feedback gain to maintain motor speed under load. It is also converted to a digital value within IC1. The capacitors at the wiper of VR1 and VR2 provide a low source impedance to IC1's ADC, and to filter out supply ripple.

Both VR1 and VR2 are connected to IC1 via screw connectors. CON2 provides the common +5V and 0V connections for VR1 and VR2, while VR1's wiper also connects



Scope5: the final output waveform of the precision full-wave rectifier is in cyan. It is identical to the yellow trace, except that the negative portions have become positive voltages, so that it can be fed to a single-ended ADC for measurement.

to CON2. CON3 provides the wiper connection for VR2, with switch S1 utilising the remaining two connections in CON3.

Mains synchronisation

The timing of the Triac's trigger pulses is critical to its correct operation. IC1 monitors the mains voltage at its pin 5, with the 330kΩ resistor connecting to neutral plus a 4.7nF low-pass filter capacitor.

An interrupt routine is triggered in IC1 whenever the voltage at pin 5 changes from a high to a low level, or vice versa. The interrupt tells IC1 that the mains voltage has just passed through 0V, so it can synchronise its gate triggering with the mains waveform.

The phase lag introduced by the 4.7nF capacitor is compensated for within IC1's software, as is the asymmetry of the triggering due to the 5V difference between low and high levels.

Current feedback

T1 is a current transformer comprising a ferrite toroid with a two-turn primary winding in series with the Triac. The secondary winding has 1000 turns, and it is loaded with a 510Ω resistor. With this loading, the transformer produces 800mV per amp of load current at the secondary output. This is proportional to the current through the motor being controlled.

Its output signal is applied to a precision full-wave rectifier comprising IC2a and IC2b. This configuration is unusual in that it does not use any diodes. Most precision rectifiers with diodes require a negative supply for the op amps. While we could have incorporated a negative supply, it would increase the circuit complexity and cost.

The full-wave rectifier operation relies on op amps that have specific characteristics. The first is that the op amp output has to swing fully to the negative supply rail (ie, all the way down to 0V). Also, this 0V output must be maintained when the input to the op amp drops below 0V. The LMC6482 op amp (IC2a and IC2b in the circuit) has these characteristics, as well as a low supply current.

We have labelled several points in the circuit and shown the expected waveforms to help explain how this section works. The signal from the transformer secondary appears at point A. This signal swings above and below 0V as shown. The signal flows along two paths from here. One is through the 20kΩ resistor to point D, and the other through the two series-connected 100kΩ resistors to 0V.

Parts list – Full-wave Motor Speed Controller

- 1 double-sided PCB coded 10102211, 103 x 81mm
- 1 diecast box, 119 x 94 x 34mm [Jaycar HB5067]
- 2 linear 50kΩ 24mm potentiometers (VR1,VR2)
- 2 plastic knobs to suit VR1 and VR2
- 1 SPST mini rocker switch (S1) [Jaycar SK0984 or Altronics S3210]
- 1 Talema AX-1000 10A current transformer (T1) [RS Components 775-4928]
- 1 M205 10A safety panel-mount fuse holder (F1) [Altronics S5992]
- 1 M205 10A fast-blow fuse
- 1 4-way PCB-mount screw terminal (CON1) [Jaycar HM-3162]
- 2 3-way PCB-mount screw terminals, 5.08mm pitch (CON2,CON3)
- 2 GP9 cable glands for 4-8mm diameter cable
- 1 8-pin DIL IC socket (for IC1)
- 1 2m-long 10A mains extension cord
- 3 chassis lugs with 4mm eyelets
- 4 6.3mm-long M3 tapped nylon spacers
- 3 M4 x 10mm panhead or countersunk machine screws (for mounting Q1; earthing)
- 2 4mm inner diameter star washers
- 3 M4 nuts
- 8 M3 x 5mm panhead or countersunk machine screws
- 4 stick-on rubber feet
- 1 20mm length of 12mm diameter heatshrink tubing
- 1 80mm length of 3mm diameter heatshrink tubing
- 1 600mm length of 7.5A mains-rated wire (for VR1, VR2 and S1)
- 4 100mm-long cable ties

Semiconductors

- 1 PIC12F617-I/P 8-bit microcontroller programmed with 1010221A.hex, DIP-8 (IC1)
(1010221A.hex software available from the 'Downloads' section of the PE shop)
- 1 LMC6482AIN dual CMOS op amp, DIP-8 (IC2)
- 1 BTA41-600B 40A 600V insulated tab Triac, TOP3 (Q1)
- 1 BC337 500mA NPN transistor, TO-92 (Q2)
- 1 5.1V 1W (1N4733) zener diode (ZD1)
- 2 1N4004 400V 1A diodes (D1,D2)

Capacitors

- 1 1000μF 16V PC electrolytic
- 1 100μF 16V PC electrolytic
- 1 10μF 16V PC electrolytic
- 1 2.2μF 16V (or higher) PC electrolytic
- 1 470nF 275VAC X2-class metallised polypropylene (value printed on body)
- 1 220nF 275VAC X2-class metallised polypropylene (value printed on body)
- 3 100nF 63/100V MKT polyester (code 103 or 100n)
- 1 4.7nF 63/100V MKT polyester (code 470 or 4n7)

Resistors (all 0.25W, 1% unless otherwise stated)

- 1 330kΩ 5% 1W carbon film
- 3 100kΩ
- 1 47kΩ
- 2 20kΩ
- 1 10kΩ
- 1 4.7kΩ
- 1 1kΩ 10% 5W wire wound
- 1 510Ω
- 1 470Ω
- 2 220Ω 5% 1W carbon film
- 1 100Ω
- 2 47Ω

Miscellaneous

Super Glue (cyanoacrylate), thermal paste, solder

IC2b is connected as a unity-gain buffer. The op amp's internal diode will clamp any voltage at the non-inverting input (pin 5) below -0.3V . Its output (pin 7) will be at 0V whenever its input is 0V or less.

The operation of this part of the circuit is best explained by describing the signal flow for the negative and positive excursions of the waveform separately.

Negative portion

When the voltage at point A is negative, the voltage at point B is clamped to -0.3V by the internal protection diode at the pin 5 input of IC2b. The out-

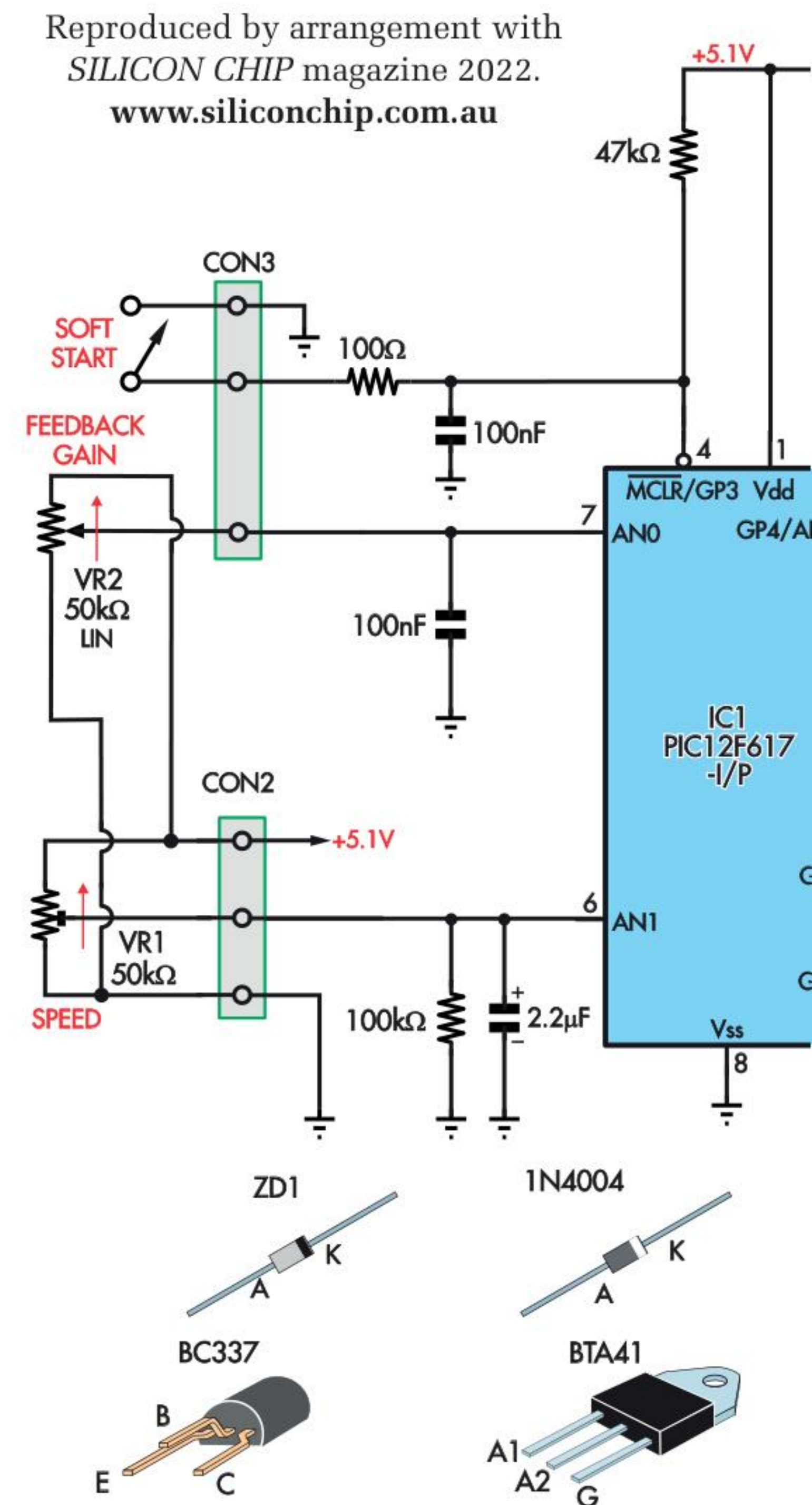
put of IC2b at pin 7 (point C) is therefore at 0V, and so is the non-inverting input to IC2a.

As a result, IC2a acts as an inverting amplifier with a gain of -1 . This is set by the input $20\text{k}\Omega$ resistor and the $20\text{k}\Omega$ feedback resistor from the pin 1 output to the inverting input at pin 2. So IC2a will produce a positive voltage at its output pin 1, proportional to the negative voltage at point A.

To understand how this works, consider that the op amp operates to keep the voltages at its inputs equal. As the non-inverting input is held at 0V, with equal-value resistors in the feedback

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path forming a 1:1 divider, the output voltage (E) must have equal magnitude and opposite polarity compared to the input voltage (A) for the inverting input voltage (D) to be at 0V.

So for example, when point A is at -1V , point E will be $+1\text{V}$, so point D will be at 0V, equal to C.

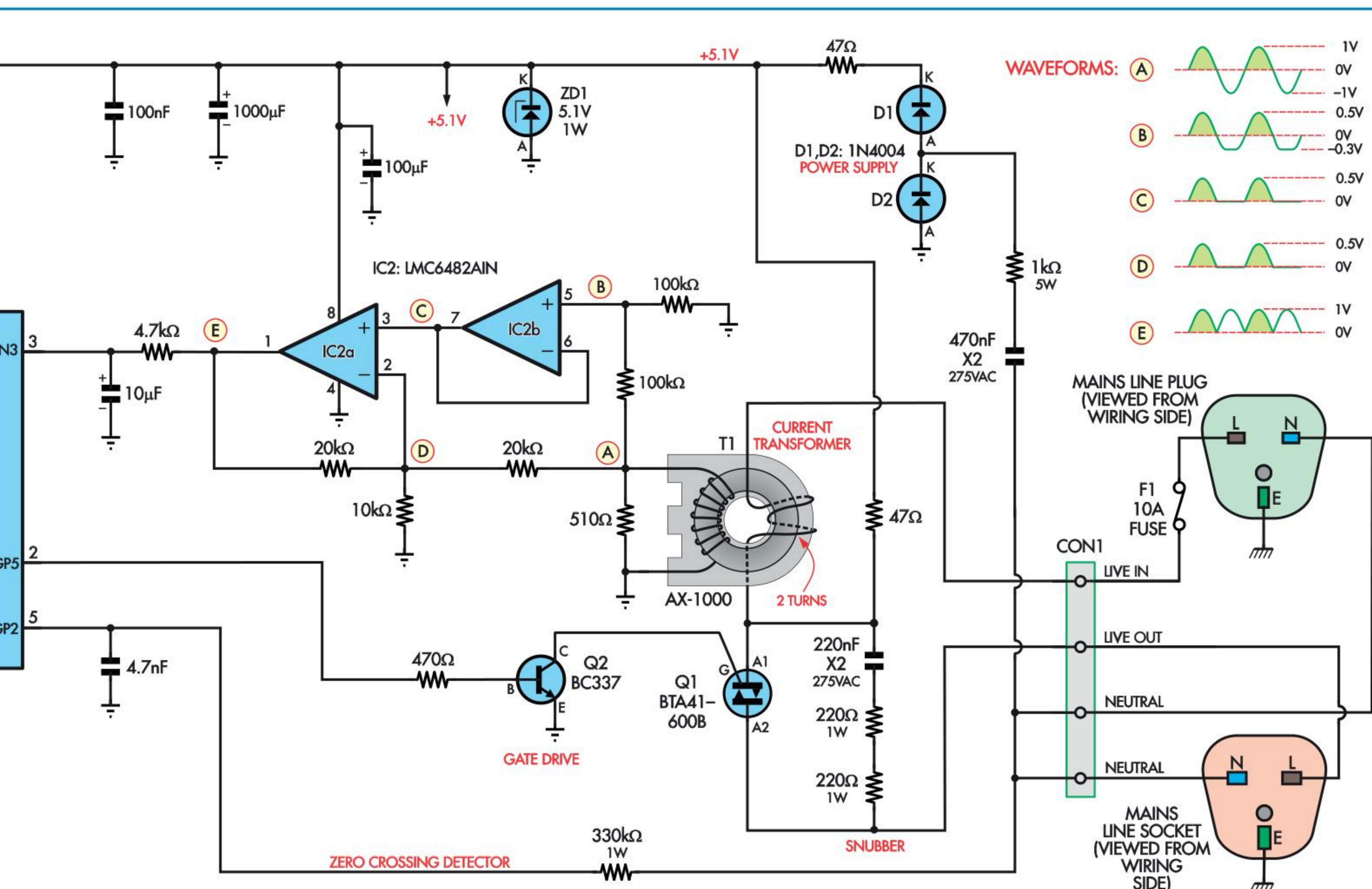
Note that the $10\text{k}\Omega$ resistor at point D does not have any effect in this example, since pin 2 is at 0V, and therefore there is no voltage across that resistor. It has a function only during positive signal excursions.

Positive portion

For positive voltages at point A, the voltage at point B will be half the voltage of point A due to the $100\text{k}\Omega/100\text{k}\Omega$ resistive divider. Point C and the non-inverting input to IC2a will also be half the applied voltage at A, as IC2b is acting as a buffer.

Remember that usually, the inverting input voltage will be the same as the non-inverting input. The op amp will ensure this by adjusting its output so it can maintain that voltage via the feedback resistor.

The only way that can happen for IC2a in this case is when the op amp



Full-wave Universal Motor Speed Controller

Fig.1: the Full-wave Motor Speed Controller uses current-sense transformer T1 and op amps IC2a and IC2b (operating as a full-wave precision rectifier) to sense the motor current. IC1 adjusts the gate pulses from its pin 2 output to the gate of Triac Q1 to maintain a more-or-less constant motor speed under load

output at point E is the same as the signal input at point A. In that case, the same voltage is applied to both 20kΩ resistors and they are essentially in parallel, forming an equivalent 10kΩ resistor to point D. This forms a 1:1 divider with the 10kΩ resistor from point D to ground, halving the voltage at this point compared to points A and E.

So, to conclude. IC2a provides the same positive voltage at its output E as the input at A during positive excursions. However, during negative excursions, IC2a instead inverts the voltage. So the output of IC2a is positive for both negative and positive inputs at point A. Thus, we have a diode-free full-wave rectifier.

Its output is low-pass filtered using a 4.7kΩ resistor and 10μF capacitor for a smooth DC output that's then applied to the AN3 analogue input of IC1, ready to be digitised.

Scope4 shows a sinewave signal at point A (in yellow) and the lower blue trace shows waveform C, the half-amplitude positive waveform output. When waveform A goes below 0V, waveform C stays at 0V.

Scope5 shows the same sinewave signal at A in yellow, together with

the full-wave rectified output at E in the lower blue trace.

Construction

Most components for the *Full-wave Universal Motor Speed Controller* are mounted on a double-sided, plated-through PCB coded 10102211, measuring 103 x 81mm and available from the *PE PCB Service*. This is mounted inside a diecast box measuring 119 x 94 x 34mm.

Follow the PCB overlay diagram, Fig.2. Begin by installing the resistors except for the 5W type – double-check each resistor using a digital multimeter. Following this, fit the diodes, which must be oriented as shown. There are two different diode types: 1N4004 for D1 and D2, and zener diode ZD1 is a 5.1V 1W type (1N4733).

IC1 is mounted on an 8-pin DIL socket so install this socket now, taking care to orient it correctly, with the notch facing towards the top of the PCB. Leave IC1 out for the time being, though; we'll fit it later. IC2 can be installed on a socket or directly on the PCB. Q2 can also be installed now.

Place the capacitors next. The MKT and polypropylene types are usually

printed with a code indicating their value. These are all shown in the parts list.

By contrast, electrolytic capacitors are almost always marked with their value in μF, along with their polarity. Typically, the negative lead is marked with a stripe. They must be inserted with the polarity shown.

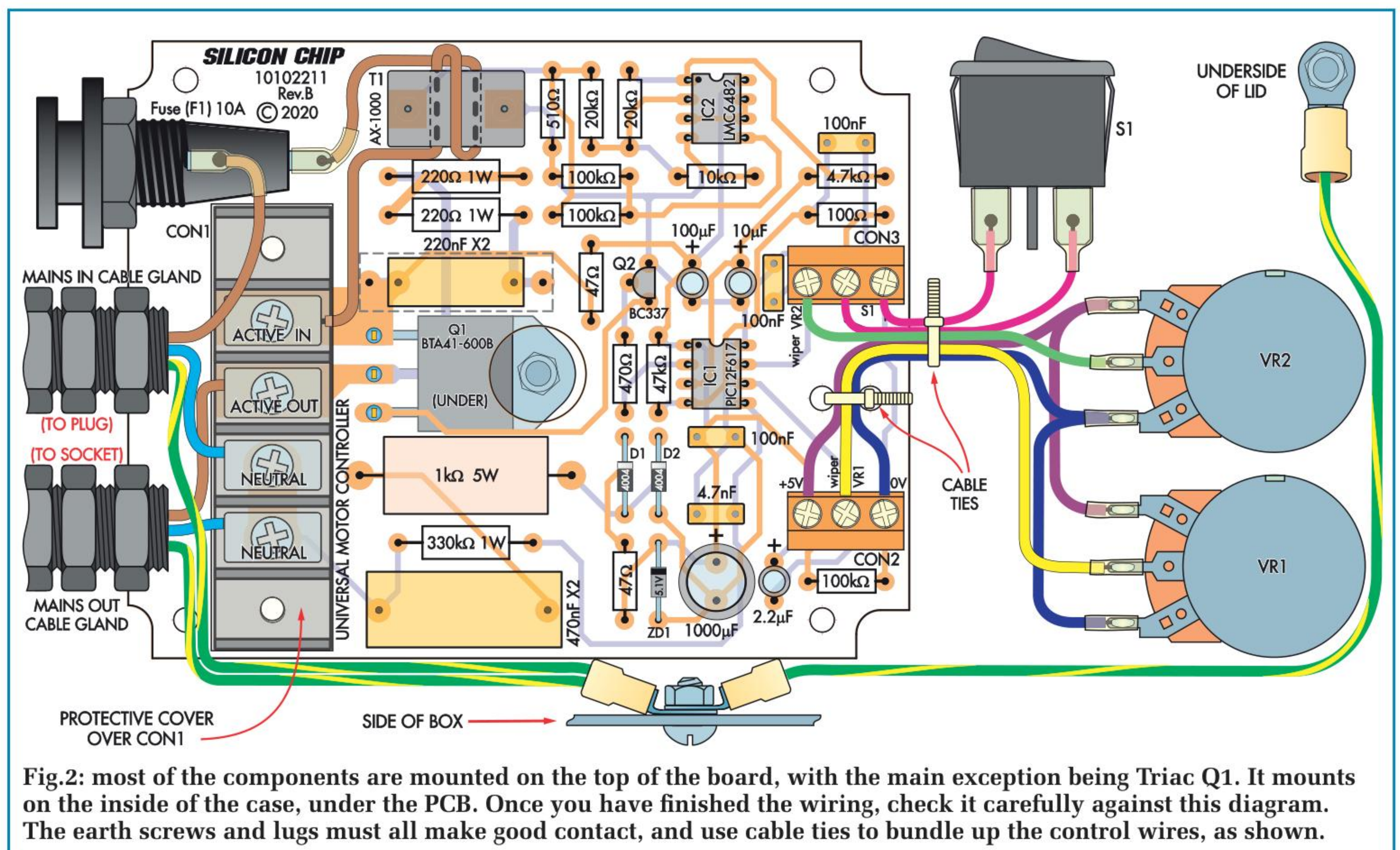
The screw terminals are next. The 3-way terminal blocks for CON2 and CON3 are installed with the lead entries facing each other, while CON1 does not have a specific orientation. Then fit the 5W resistor about 1mm above the PCB for improved cooling.

Finally (for now), install current transformer T1. It does not matter which way it is oriented. Triac Q1 will be fitted later.

Cut the underside pigtail leads from all components short to prevent contact with the base of the case.

Drilling the case

Fig.4 shows a template/guide for drilling the case. The lid requires 9.5mm diameter holes for potentiometers VR1 and VR2, a 19mm x 10mm rectangular cutout for switch S1 and a 4mm hole for the earth screw.



The PCB is mounted in the base of the case using 6.3mm-long M3 tapped spacers, which require mounting holes.

Use the PCB as a template, and note that the CON1 screw terminal end sits further away from the end of the box compared to the other end. This allows space for the cable gland nuts. With the PCB in place, mark out the hole positions, remove it and drill them to 3mm.

Attach the 6.3mm-long spacers to the PCB using short machine screws, then bend the Triac leads up by 90°

4mm from its body. Insert the leads into the PCB from the *underside* (see Fig.2 and Fig.3).

Secure the PCB to the case with screws from the underside and mark the Triac mounting hole position on the base of the case. Remove the PCB again and drill this to 4mm. Clean away any metal swarf and slightly chamfer the hole edges, then reattach the PCB and adjust the Triac lead height, so the metal tab sits flush onto the flat surface.

Secure the Triac tab to the case with an M4 screw and nut. The metal tab is internally isolated from the leads, so it does not require any further insulation between its tab and the case.

Solder the Triac leads on the top of the PCB and trim them close. Now remove the screws to gain access to the underside of the PCB and solder the Triac leads from the underside of the PCB as well.

Now is a good time to attach rubber feet to the base of the case.

Panel preparation

As well as drilling the holes in the lid mentioned above, you need to partially drill a 4mm hole on the inside for the pot location pin that prevents the pot body from rotating. Drill it so that it almost reaches the outside of the lid, but doesn't go all the way through.

If you use a countersunk-head earth screw and countersink its hole appropriately, it can be mounted under the panel label for a neater appearance. Otherwise, you'll need to cut a hole in the panel label (with a sharp hobby knife) when the label is stuck on.

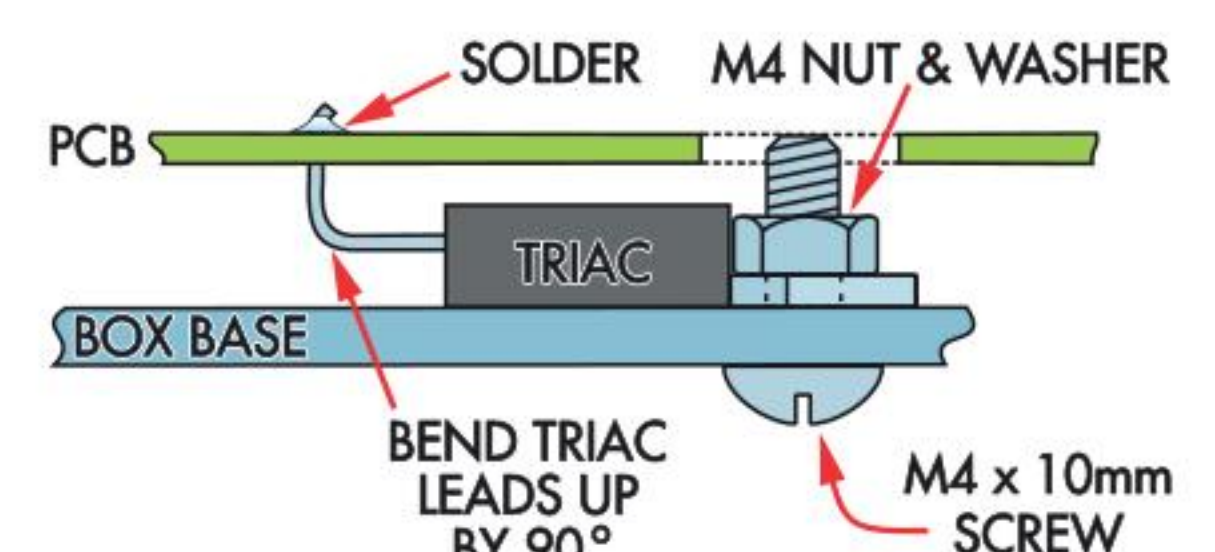
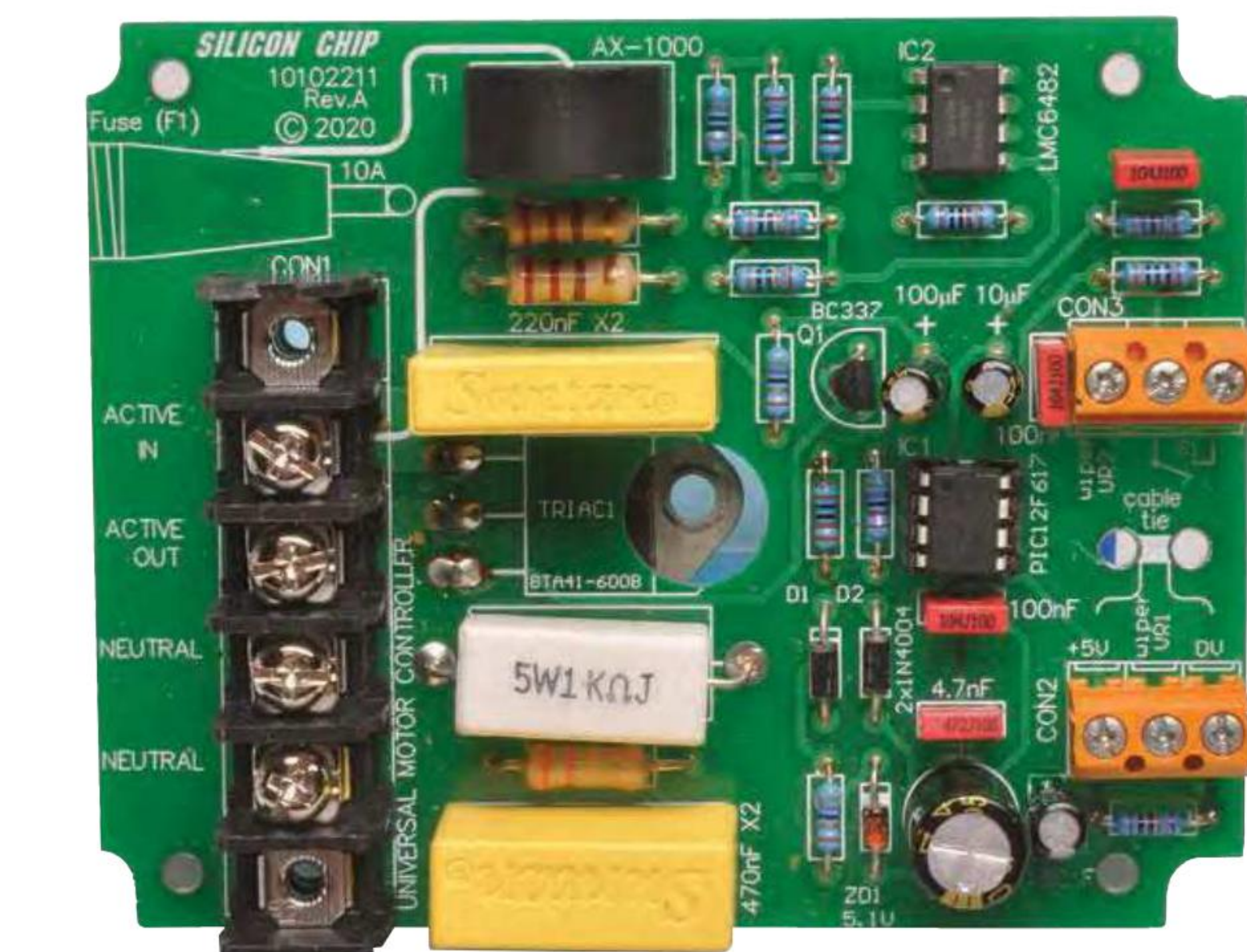


Fig.3: Triac Q1 mounts on the base of the case, using it as a heatsink. A hole in the PCB gives access to hold the nut while you tighten the screw.



Close-up, same-size photo of the Speed Controller PCB. Because it is a mains-powered and mains-controlling device, your construction must be exemplary. Don't attempt this project if you're not experienced with mains devices.

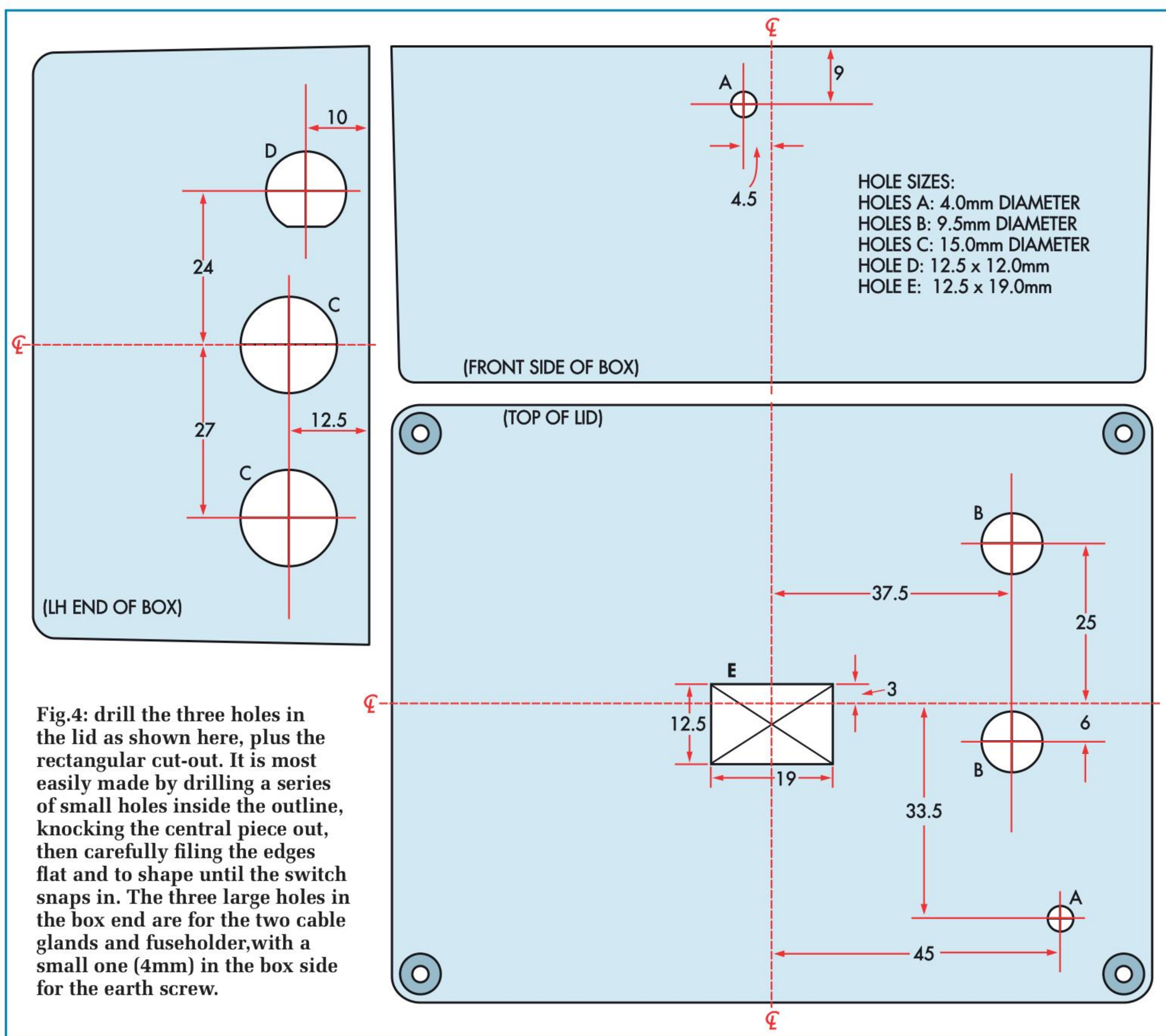


Fig.4: drill the three holes in the lid as shown here, plus the rectangular cut-out. It is most easily made by drilling a series of small holes inside the outline, knocking the central piece out, then carefully filing the edges flat and to shape until the switch snaps in. The three large holes in the box end are for the two cable glands and fuseholder, with a small one (4mm) in the box side for the earth screw.

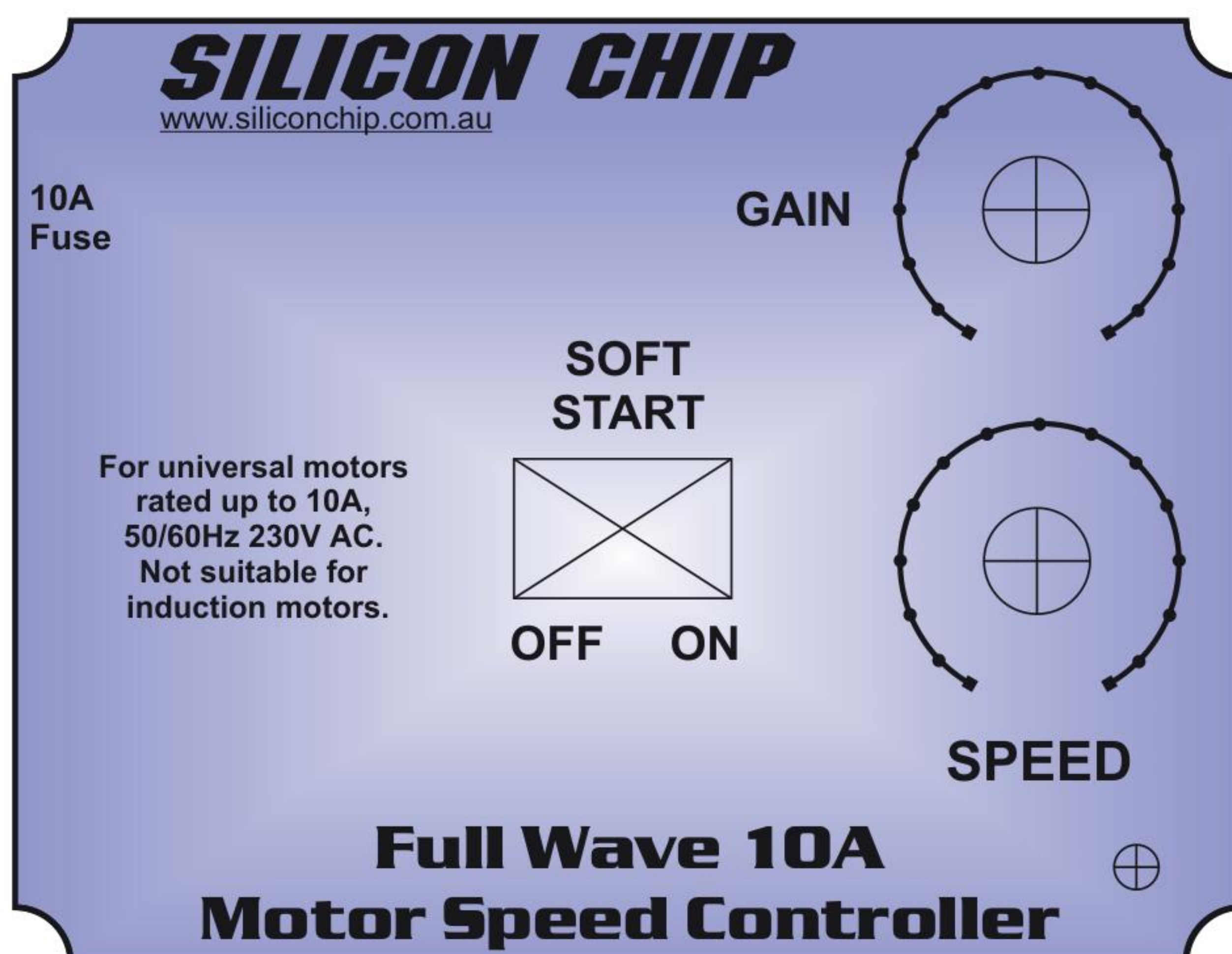


Fig.5: full-size front-panel artwork which can be copied or downloaded (from the June 2022 page of the PE website) and printed. This is glued to the top of the diecast box – and it can also be used as a template to drill the three panel holes and cutout for the soft start switch.

The panel label file can be downloaded from the June 2022 page of the *PE* website and printed. To produce a front panel label, you have several options. For a more robust label, print as a mirror image onto clear overhead projector film (using film suitable for your type of printer). Attach the label, printed side down, to the lid with a light-coloured or clear silicone sealant.

Alternatively, you can print onto a synthetic sticky label that is suitable for inkjet printers, or a sticky label for laser printers. Then affix the label using the sticky back adhesive.

Wiring

Cut the 10A extension lead into two, to provide one lead with a plug and another with a socket. Where you cut the lead depends on how long you want each section to be. You might prefer a long plug cord and short socket lead, so the appliance is located near the *Controller*, or the lead can be cut into two equal lengths.

Before cutting, make sure you have sufficient length to strip back the insulation as detailed in the next two paragraphs. Make sure the two leads are fed through the correct gland and wired, as shown in the wiring diagram, Fig.2.

For the socket (output) lead, you need a 100mm length of earth wire (green/yellow stripe) for the connection between the chassis and lid, so strip back the outer insulating sheath by about 200mm. Cut the live (brown) and neutral (blue) wires to about 50mm long and keep the off-cuts.

The spare 150mm brown wire can be used later, to connect from the fuse to CON1 via the transformer, T1. Recall that this requires two turns of the live wire looped through the transformer hole.

The 100mm earth wire (green/yellow stripe), which is routed around the edge of the PCB, and twisted together with the earth wire from the plug (input) lead, needs to be crimped into one of the earth lugs.

Strip the plug lead outer sheath insulation back to expose 100mm of wire. All three wires pass through the cable gland and connect it as shown in Fig.2. Cut the neutral wire to 50mm and strip back the insulation before connecting it to the terminal block. Now mount the fuse holder in the hole you made earlier and prepare to solder the live (brown) wire to it, as shown.

But before doing that, slide 10mm diameter heatshrink tubing over the live (brown) wire. After soldering that wire, slide the tubing up and over the fuse holder to cover the fuseholder side terminal and shrink it.

Similarly, use 3mm-diameter heatshrink tubing to cover the fuse holder end terminal after soldering that wire.

Now twist the ends of the input earth (green/yellow stripe) wire and the output earth wire together and crimp both into one of the eyelet lugs.

Cut VR1 and VR2's shafts to 12mm long from the front of the pot bodies and file the edges smooth. Then attach the three 100mm lengths of 7.5A mains-rated wire to the three terminals of VR1, plus a fourth 100mm wire to the middle terminal of VR2. Use short lengths of the same wire to connect the two ends of VR2's track to the same terminals on VR1. Cover all six terminals with 3mm heatshrink tubing.



This 'opened out' photo matches the PCB/wiring diagram on P42. Of course, we made sure that the Controller was not plugged into mains power before removing the lid!

Next, connect the free ends of these wires to CON2 and CON3, making sure you follow the layout in Fig.2. You now need to wire up switch S1 in a similar manner. It is simply wired to the two remaining terminals in either order.

Now secure all these wires to the PCB using a cable tie that feeds through the holes provided in the PCB. Attach VR1, VR2 and S1 to the lid of the case, noting that the potentiometers must be located as shown (ie, with their leads emerging away from the edge of the case). This is so that they will fit between the two mains-rated capacitors on the PCB.

Add cable ties around the wire bundles closer to VR1, VR2 and S2 as well.

Fit the knobs now; you might need to lift out the knob caps with a hobby knife and re-orientate them so that the pointers match the rotation marks on the lid panel.

That 100mm length of earth wire you cut off from the output lead can now be crimped into two eyelet lugs, which are screwed to the underside of the box lid and the earth screw on the side of the case using M4 screws, star washers and nuts. Ensure that the nuts are fully tightened.

Final assembly

Apply a smear of thermal paste to the underside of the Triac tab before installing the PCB inside the case. As mentioned, the tab of the Triac is insulated, so it can contact the case.

The last components to insert are IC1 (taking care it is oriented correctly), the 10A fuse into its holder and the cover for the barrier terminals (CON1). This is simply pressed on to

cover the screw terminals. Finally, rotate VR2 fully anticlockwise to initially disable feedback.

Now check your construction carefully. Verify that the earth wires (green/yellow striped) connect together the case, to the lid and the earth pins on both the mains plug and socket. Check this with a multimeter set to read low ohms. You should get readings below 1Ω between all earth points.

The cable glands need to be tightened to hold the mains cords in place. Because these are easily undone, apply a drop of Super Glue to the thread of the glands before tightening. That way, the glands cannot be undone by children or other curious people.

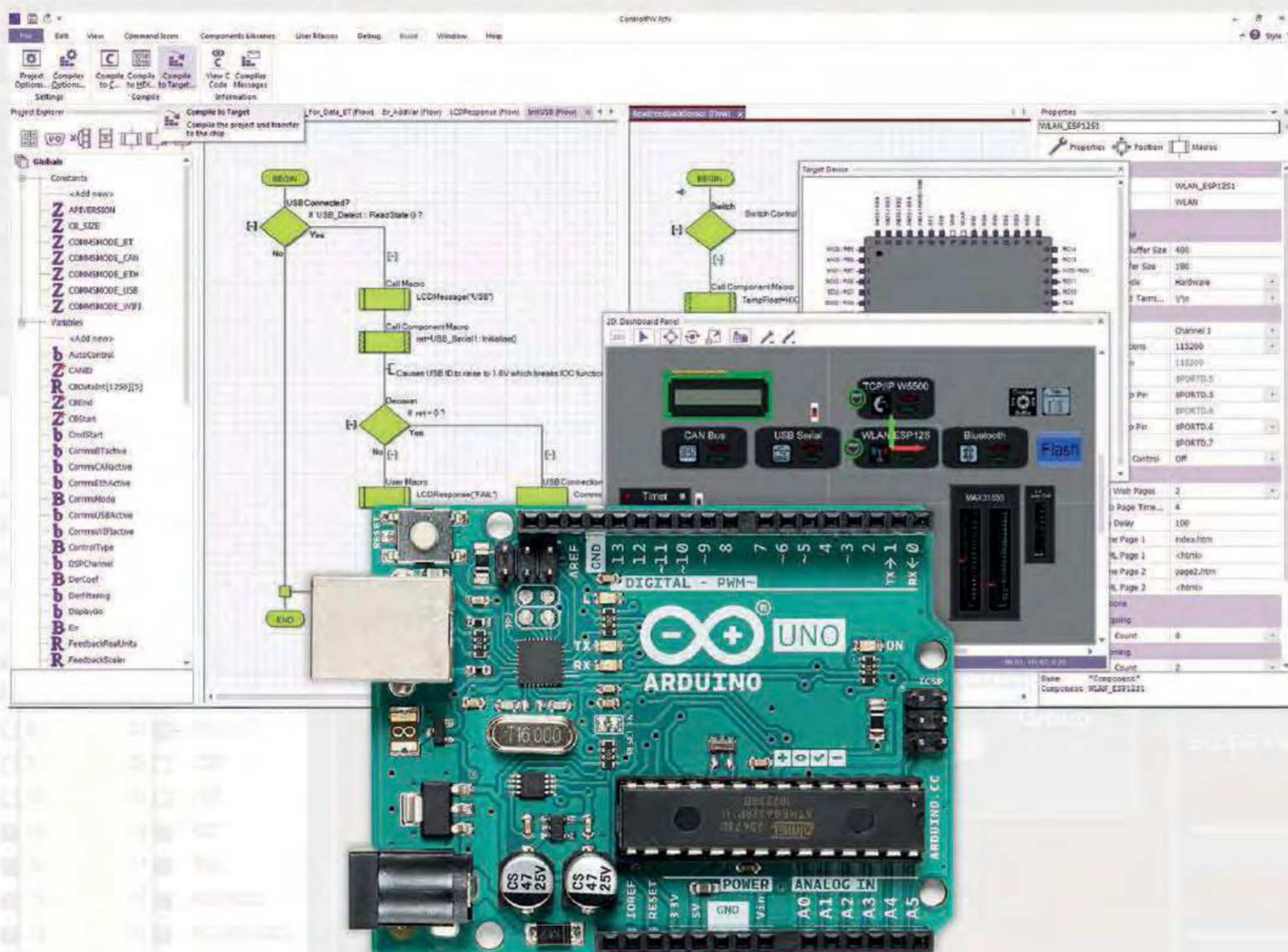
Attach the lid, ensuring the wiring is routed so that it fits around the higher components on the PCB. Use the four screws supplied with the case; don't be tempted to run the *Speed Controller* without the lid in place!

Testing

Now it's test time! Connect up a universal motor appliance (eg, a mains-powered electric drill) to the *Controller*, apply power and check that the motor can be controlled when adjusting the speed potentiometer.

VR2 may need adjustment to avoid speed changes when under load. Rotate it clockwise if the speed drops off too markedly under load, and anticlockwise if the motor speeds up under load.

Check that the soft-start feature works when enabled by switching the power off, letting the tool spin down, then switching it on again to verify that it ramps up smoothly with S1 in the correct position.



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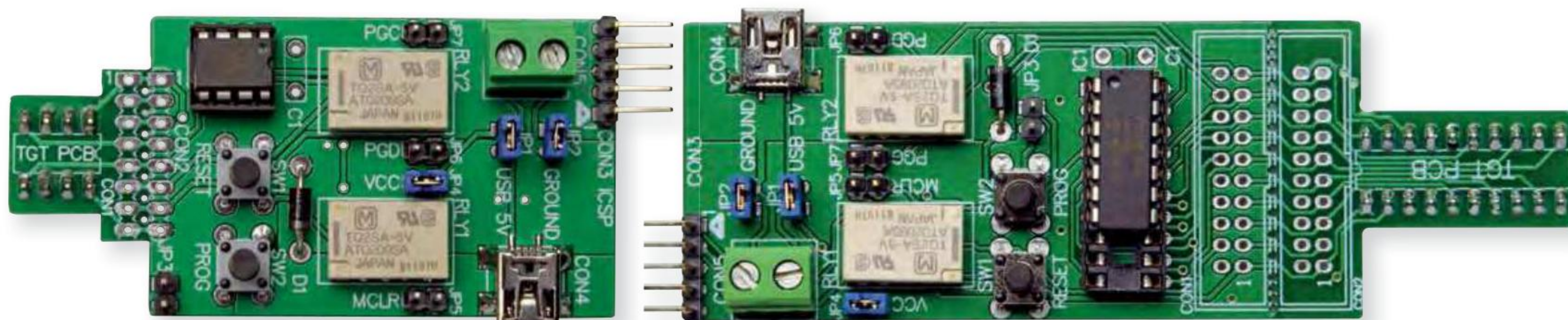
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**8-pin
14-pin
20-pin**



PIC PROGRAMMING HELPER



It's incredible what you can achieve with an 8-pin microcontroller. However, programming and debugging these chips can be a challenge due to the need to use the programming and reset pins for other purposes. This little board makes working with these (and some larger) PICs much easier!

We have included 8-pin PIC microcontrollers in many of our projects because they are very handy for doing certain jobs, and cheap to boot. Apart from a handful of 6-pin parts, which are only available in SMD packages, they are some of the smallest microcontrollers around.

For example, we used a PIC12F617 in projects such as the *Car Radio Dimmer Adapter* (September 2020), the *MiniHeart Heartbeat Simulator* (January 2022) and the *Full-wave Universal Motor Speed Controller* in this month's issue.

If you only need five or six I/O pins, then devices like these are handy and compact, while still being computationally very capable. John Clarke even used one to replace a hard-to-get rotary switch with a potentiometer in the *Digital Effects Pedal* from April and May 2022.

But consider that once you subtract the power pins, you're left with at most six I/Os, and you usually need three of these (MCLR, PG[E]D and PG[E]C) for programming and debugging. Unless your application only needs three I/Os, you will inevitably end up sharing some of these pins' functions. These shared connections can cause significant hassles.

This became apparent as we worked on an upcoming project that pushes a PIC12F1572 to its limits, using five I/O pins and running the processor at its highest operating frequency.

Some background

Microchip PIC microcontrollers have long used a five-wire programming interface. The voltages and protocol have varied over the years, but these five wires have always performed broadly the same roles.

The PICkit 2 and PICkit 3 programmers both sport six-way headers; the later PICkit 4 and Snap programmers have eight-way headers. This is because these programmers now support Microchip parts that do not belong to the PIC family, such as AVR and SAM devices which came into Microchip's stable with their 2016 purchase of Atmel.

While the exact pin mapping of these five wires varies between PIC families and pin counts, the small number of pins on the 8-pin parts means that there are not many permutations.

The purpose of the *PIC Programming Helper* device we have developed is to switch the function of some pins on your micro between programming/debugging and application-specific I/Os during development. This will make your life much easier.

While we can't promise that this Helper will work with all 8-pin PICs, it should work with most. The main exception we're aware of is PIC10F parts (some of which come in 8-pin packages, but only six are connected).

Table.1 shows the five connections used for PIC programming, their order on the programming header and what pins they connect to on an 8-pin PIC. Note that the ground pin is located

in the centre of the group, reducing the chance of damage if the header is reversed.

One way to re-use pins 4, 6 and 7 on an 8-pin PIC is to mount it in a socket on the board, then when you need to program it, unplug it and insert it into a programming socket. After programming, it can be re-inserted into the original socket on the board.

But this can quickly become tedious as the chip is repeatedly moved between the programming socket and the test circuit. It also means you can't perform in-circuit debugging (ICD).

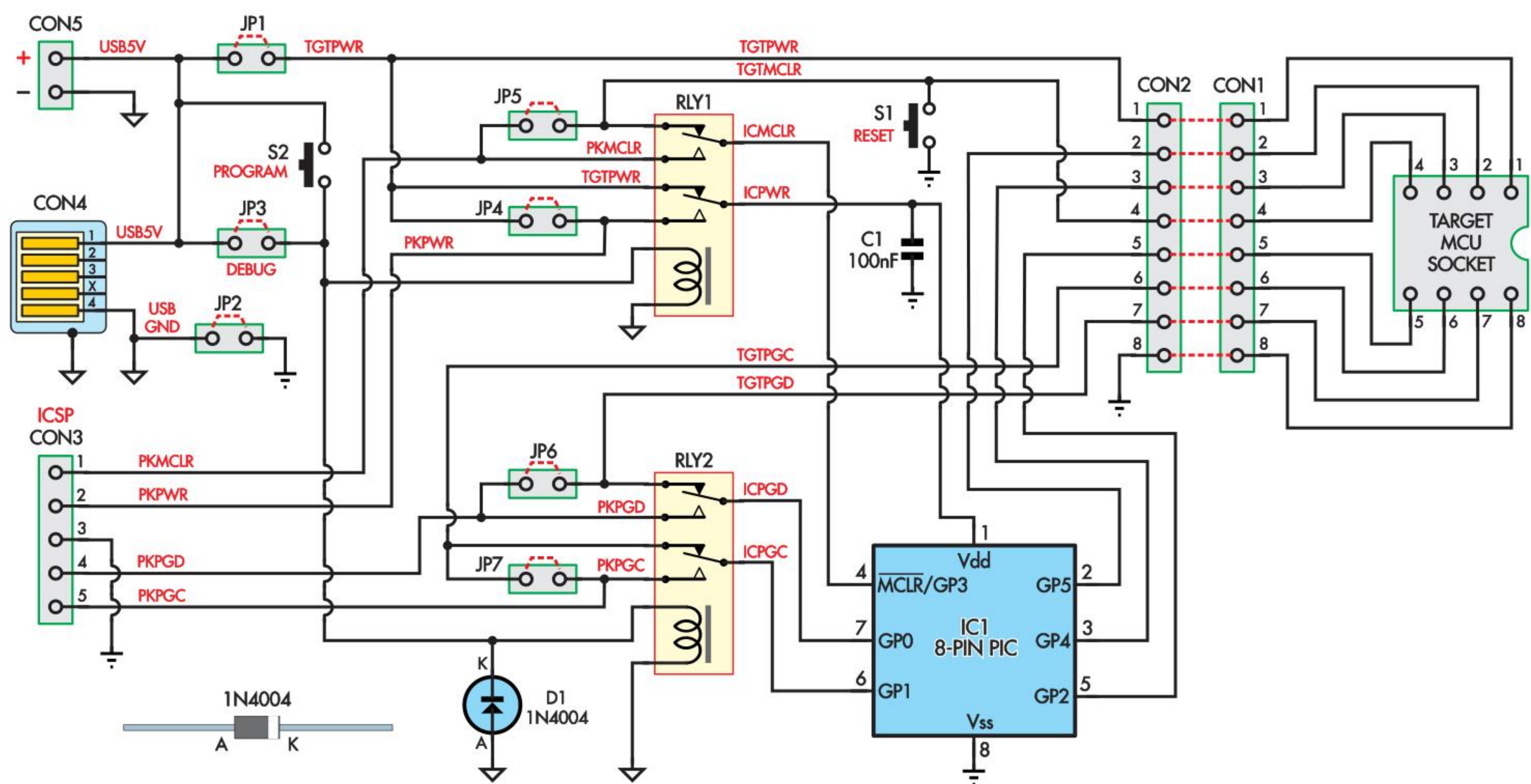
The alternative is so-called ICSP (in-circuit serial programming), which allows the chip to stay in place and be programmed 'in circuit'. But this might not be possible when pins 4, 6 or 7 need to be used for the project at hand, depending on how they are used.

Pins 6 and 7 are usually fully featured; in the case of the PIC12F1572, they can be used as analogue inputs to the ADC (analogue-to-digital converter), comparator or as PWM outputs. In most cases, MCLR can also be used as an input, if desired.

In our recent design using the PIC12F1572, we used pins 6 and 7 as analogue inputs to sense the rotation of potentiometers, so both are connected to a low-impedance analogue voltage source. This prevents successful in-circuit programming.

Also note that some programming modes apply up to 13V to the MCLR pin (pin 4). If this is being used as an input,

BY TIM BLYTHMAN



8-pin PIC Programming Helper

Fig.1: most of the circuitry is for switching the pin connections for PIC chip IC1 between the ICSP header (CON3) and the TGT PCB pads, which plug into a development board. S2 is used to energise the relays. The board can be split between CON1 and CON2 to allow some distance between the circuits if necessary.

anything else connected to it must handle this during in-circuit programming.

A solution to this issue is that some PIC parts are available with a so-called debug header variant. This is a specialised part with extra pins to separate the programming and debug functions from the other pin functions. A board fitted with jumpers often allows the header to emulate different parts.

But these parts are much more expensive than their off-the-shelf counterparts, as might be expected for something that sees very limited production. And they are not available to suit all PIC parts.

An example is the AC244053, which can emulate the PIC16F1454, PIC16F1455 or PIC16F1459. This specialised chip is a 28-pin SOIC (SMD) device, necessary to provide all 20 pins

of the PIC16F1459 plus the separate debugging/programming pins.

You can purchase it from the Digi-Key website for around £50 (search [digikey.co.uk](https://www.digikey.co.uk) for 'AC244053').

Our solution

For a slightly cheaper and more generic solution, we've designed a tool that works with most 8-pin PIC micro-controllers. We use a set of relays to switch between the programmer and the target PCB, ensuring only one is connected at a time.

This removes conflicts, ensuring that the pins are dedicated to only one role at a time. So you can easily switch between programming the chip and testing its functions. Note, though, that it might or might not allow you to use in-circuit debugging; it depends on whether your code will still work

with the debugging pins disconnected from their other roles.

While debugging a semi-functional circuit is annoying, we have done so in the past and successfully fixed difficult bugs in our code. You might need to temporarily modify the code to ignore the state of the dual-use pins; that's still better than not being able to use in-circuit debugging at all!

Fig.1 shows the circuit diagram of the *PIC Programming Helper*. In a similar vein to the debug header, the Helper has a set of pins that slot into a DIL socket on the target PCB, where the programmed chip will go when development is complete.

This header is marked TGT PCB, and its pins run to the headers marked CON1 and CON2. We'll explain what these are for shortly. Pins 1, 4, 6 and 7 of the TGT PCB header are wired to the normally-closed contacts of 5V DPDT miniature telecom relays RLY1 and RLY2.

The common contacts of RLY1 and RLY2 are wired back to IC1, which is where a real 8-pin PIC will be installed during development. Pins 2, 3, 5 and 8 of the TGT PCB header are also connected to the corresponding pins of IC1.

This socket and header combination is our 'emulated' chip. When RLY1 and RLY2 are not energised, the target circuit will behave as though it has a PIC chip directly plugged in.

The normally-open contacts of RLY1 and RLY2 are wired back to the

Table.1: PICkit programming header and 8-pin PIC pin mapping

Header pin	Pin on PIC	Label	Role
1	4	MCLR	Master clear and reset. It can also be used to apply V_{PP} (above 5V) to enable programming mode on the attached chip.
2	1	V_{CC}	Power, which could be provided by the programmer or the connected circuit.
3	8	GND	Circuit ground
4	7	PGD	Programming data signal; driven by the programmer during writes and driven by the chip during reads.
5	6	PGC	Programming clock signal, usually driven by the programmer.

ICSP header (CON3, along with the ground connection, pin 8, from IC1). When the relays are energised, IC1 is connected to the ICSP header, allowing it to be programmed.

Mini-USB socket CON4 and screw terminal CON5 allow 5V to be provided, via S2, to the coils of RLY1 and RLY2 so that the switchover can be effected by holding down push-button S2.

D1 is the back-EMF suppression diode for the relay coils.

So far, we have described the critical parts of the *PIC Programming Helper* that provide trouble-free programming. But since we've gone to the trouble of designing a PCB, we thought we'd add a few more features.

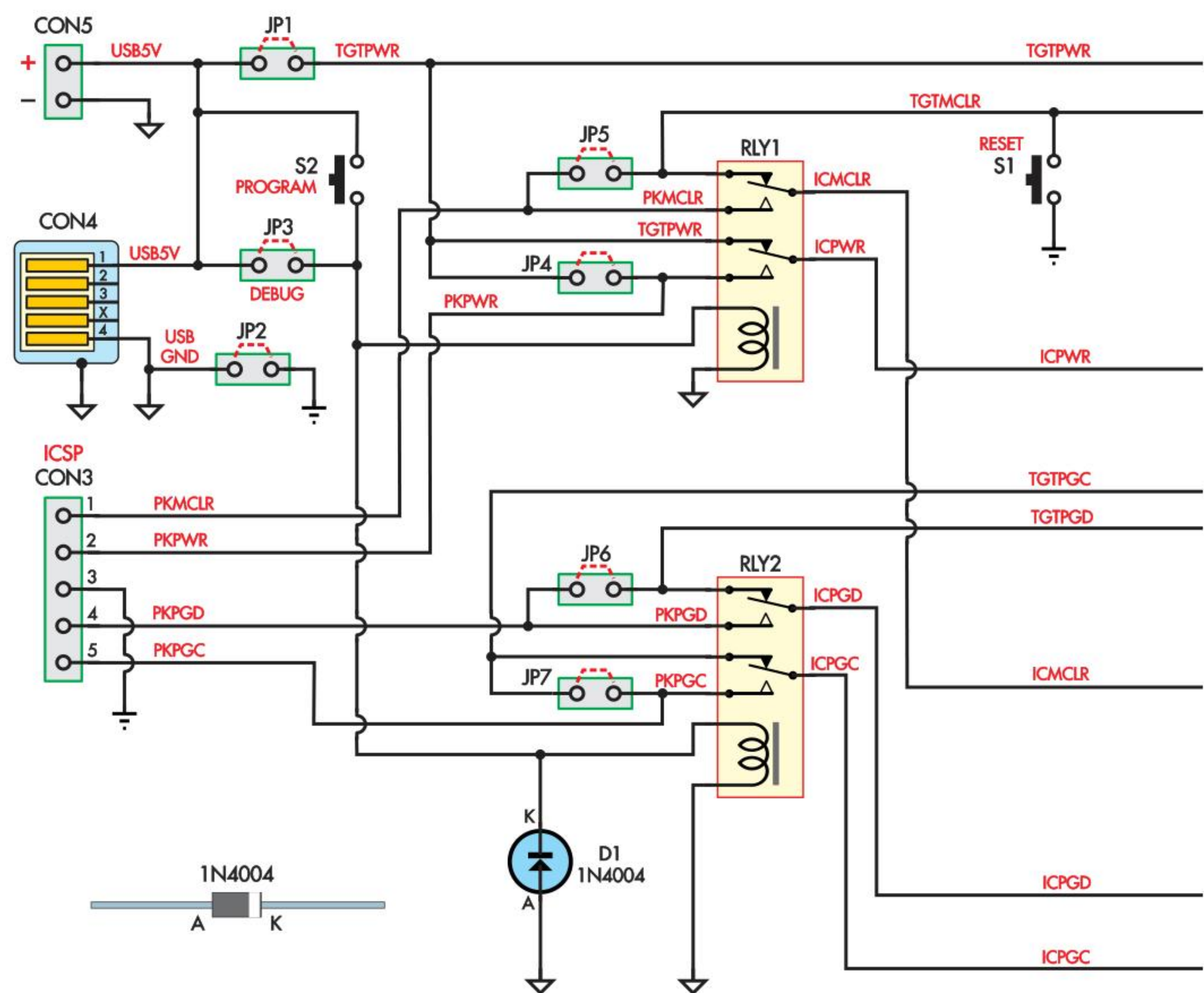
CON1 and CON2 are wired straight through, and the PCB can be scored between these connectors, allowing it to be broken apart and the two parts wired together (eg, using a ribbon cable).

The need to have the two parts physically distant is handy, but we found a degree of mechanical separation was also very useful. The TGT PCB header is a fair but not firm fit into a standard IC socket, so having the flexible wire connection allows some movement of the main PCB without affecting the seating of the emulated IC.

You could also use the pads of CON1 or CON2 to wire directly to your development system's PCB if it isn't an 8-pin DIP part. For example, enamelled copper wire could be soldered directly to the pads of a SOIC (or smaller) IC footprint.

Both CON1 and CON2 have their pins arranged to match the standard numbering used on 8-pin chips for simplicity.

If bridged, JP1 and JP2 connect the relay power circuit (CON4 and CON5) to the target circuit. We joined these to allow the relay to be powered by our



8/14/20-pin PIC Programming Helper

programmer, so we don't need to supply power via CON4 or CON5. Note that this requires JP4 (see below) to be closed too.

JP3 is connected across S2's contacts, so it provides a slightly more permanent way of setting the relays to the programming position. You could also use this to connect an external toggle switch if you prefer something with a non-momentary action.

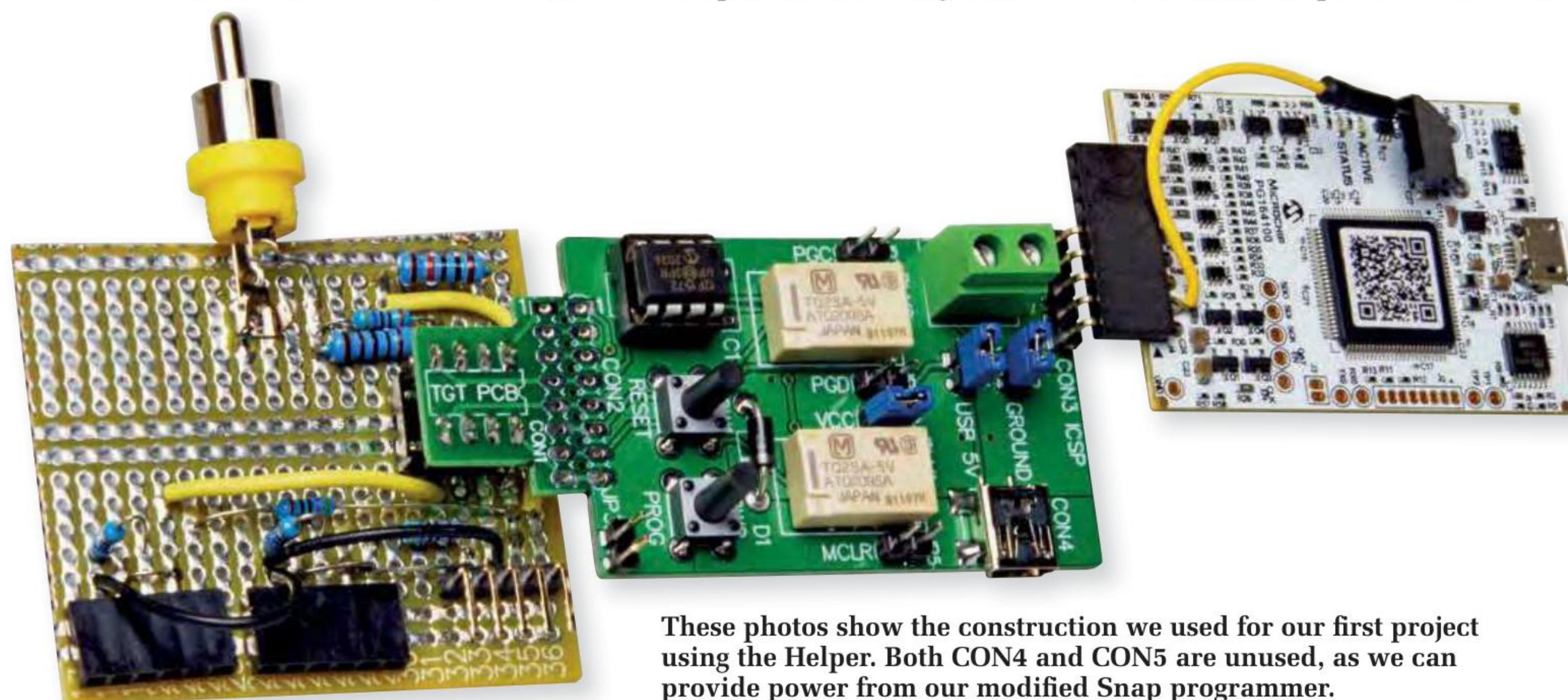
JP4-JP7 can bridge the relay contacts of the V_{CC} , $\overline{MCLR}$, PGD or PGD lines, respectively. We jumpered out V_{CC} in our rig to prevent the IC from losing power as the relay contacts change over. Still, you might prefer to leave it open to allow any other

circuitry to fully reset after a programming sequence.

S1 simply connects the $\overline{MCLR}$ pin to GND, resetting the microcontroller under normal conditions. It shouldn't be pressed while S2 is active (and the programmer is driving the $\overline{MCLR}$ line), but it's often handy to reset the microcontroller while testing.

We've also provided a position (marked C1) for a bypass capacitor for IC1. Since the target circuit will usually have provision for this, it is not normally necessary. We didn't populate it in our prototype.

Depending on the load incurred by your circuit, this capacitor could be used to maintain power to IC1 while



These photos show the construction we used for our first project using the Helper. Both CON4 and CON5 are unused, as we can provide power from our modified Snap programmer.

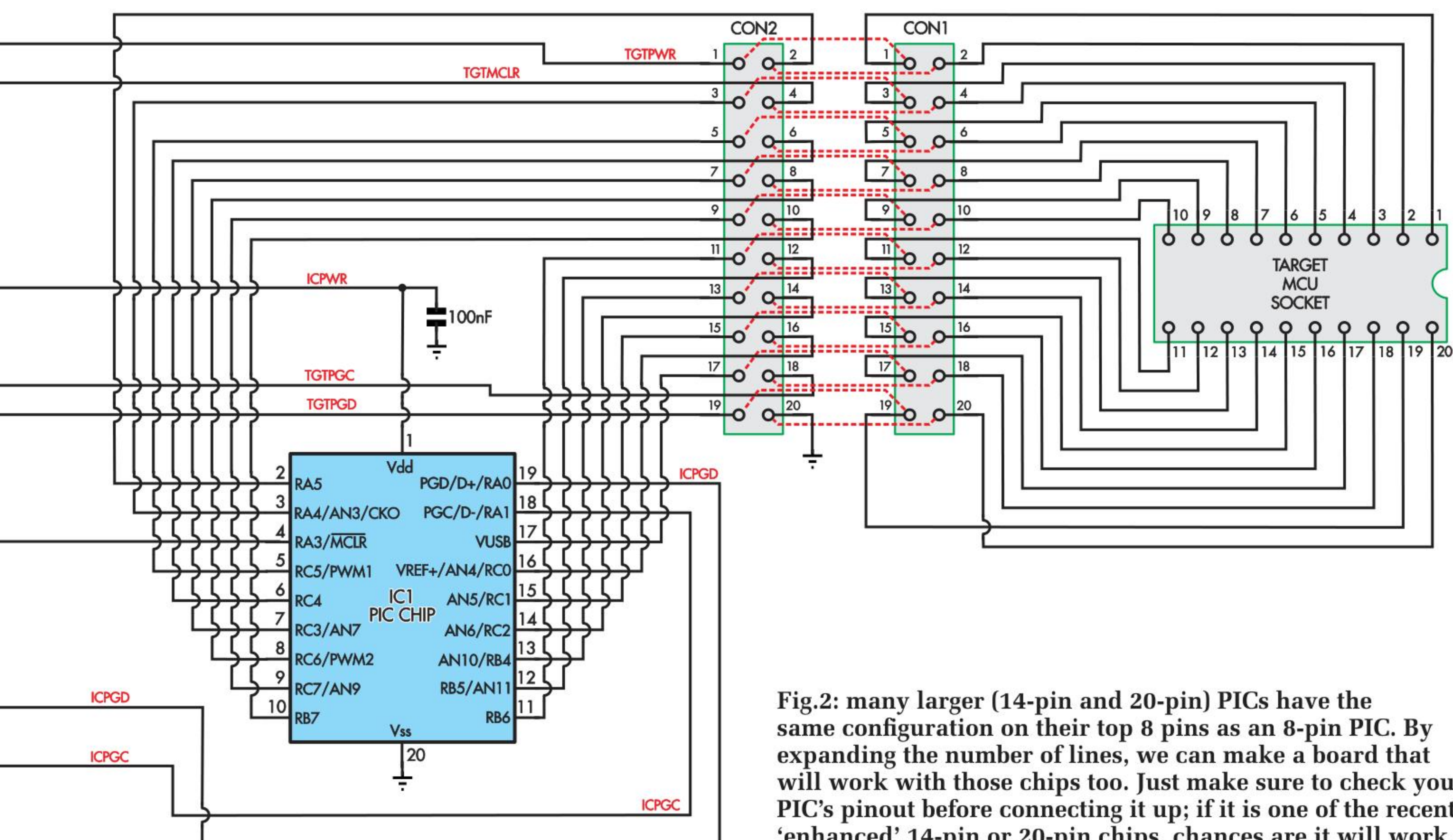


Fig.2: many larger (14-pin and 20-pin) PICs have the same configuration on their top 8 pins as an 8-pin PIC. By expanding the number of lines, we can make a board that will work with those chips too. Just make sure to check your PIC's pinout before connecting it up; if it is one of the recent 'enhanced' 14-pin or 20-pin chips, chances are it will work.

the relay contacts change over. The capacitance needed for this to work depends heavily on the circuit current draw and switching time.

The specified relays are rated to switch in about 4ms, so for example, if your circuit (including the micro-controller) typically draws 20mA, you would need 47µF to keep the supply voltage from dropping below 4V during that 4ms period, or 22µF to prevent it from falling below 3V. You can scale the capacitor value proportionally for heavier or lighter current loads.

Handling larger chips

Despite having more I/Os, larger chips such as those with 14 or 20 pins can still suffer from the same problems as 8-pin chips. We tend to use all the pins for something, regardless of how many there are, which means that we often have to be careful what we connect to the programming pins.

The good news is that many 14-pin and 20-pin PICs use the same pinout as the 8-pin types, just with more pins added below. So all we have to do to make the *PIC Programming Helper* usable with these devices is to expand the PCB slightly, adding extra pins on both the socket for IC1 and the target chip header, as shown in Fig.2.

CON1 and CON2 change to DIL headers to accommodate the extra pins, allowing a ribbon cable with standard IDC inline sockets to join the two boards if split apart.

Note that 18-pin parts like the PIC16F88 that we've used for many years (but no longer recommend for new designs) has a different pinout from the newer 'enhanced' range of PICs, so it and similar chips will not work with this project.

Most chips with more than 20 pins use a different pinout, and many of these devices are also wider, so we didn't think the compromises necessary to make this board support them were worthwhile.

Construction

The 8-pin *PIC Programming Helper* is built on a double-sided PCB coded 24106211 and available from the *PE PCB Service*. It measures 37 x 72mm, with a narrowed section at one end. Refer to the PCB overlay diagram, Fig.3, during construction.

The 14/20-pin version (which also supports 8-pin PICs) uses a PCB coded 24106212 which is 37 x 105.5mm (Fig.4) – available from the *PE PCB Service*. The assembly procedure for the two boards is essentially the same.

If you intend to separate the PCB between CON1 and CON2, do this now so that no components are damaged.

Carefully score both sides of the PCB to break the copper connections. This will reduce the chance of tearing them off the PCB.

Then, while firmly holding the larger half of the PCB in a vice or pliers, flex the smaller (CON1) half of the PCB with pliers along the line.

Once the PCB separates, you can tidy up the rough edges with a file. Take care to do this in a ventilated area (such as outside) to minimise inhalation of the resulting glass fibre dust.

The first part to fit is the mini-USB socket (CON4), as it's the only surface-mounted part. Some flux paste is handy, but since only the two outer power pins need to be connected, you could get away without it.

Apply flux to all the pads and slot the connector into the holes in the PCB. Solder the smaller pads to the PCB. We've extended the two mandatory (power) pads to make this easier. If you created any solder bridges, remove them using solder wicking braid and a bit more flux paste.

Then solder the four larger pads to the PCB to mechanically secure the part. Some time and heat may help here due to the larger metal mass. Clean up any excess flux at this point.

Fit diode D1 next, noting the location of the cathode band. Then install the relays. They will have a stripe on their body to indicate the pin 1 end, or perhaps have a pin 1 dot like an IC. This end goes nearest the diode, as shown in Fig.3 and Fig.4. Solder two leads to secure the relays roughly in place and adjust them to be flat against the PCB one lead at a time. Finally, solder the remaining pins.

We recommend using a socket for IC1 so that the PIC chip can be changed when necessary. Our photos show the socket fitted with a PIC12F1572 for our

current project in progress. Use the technique described above to ensure that the socket is flat.

The seven jumpers (JP1-JP7) are simply two-pin headers. These can

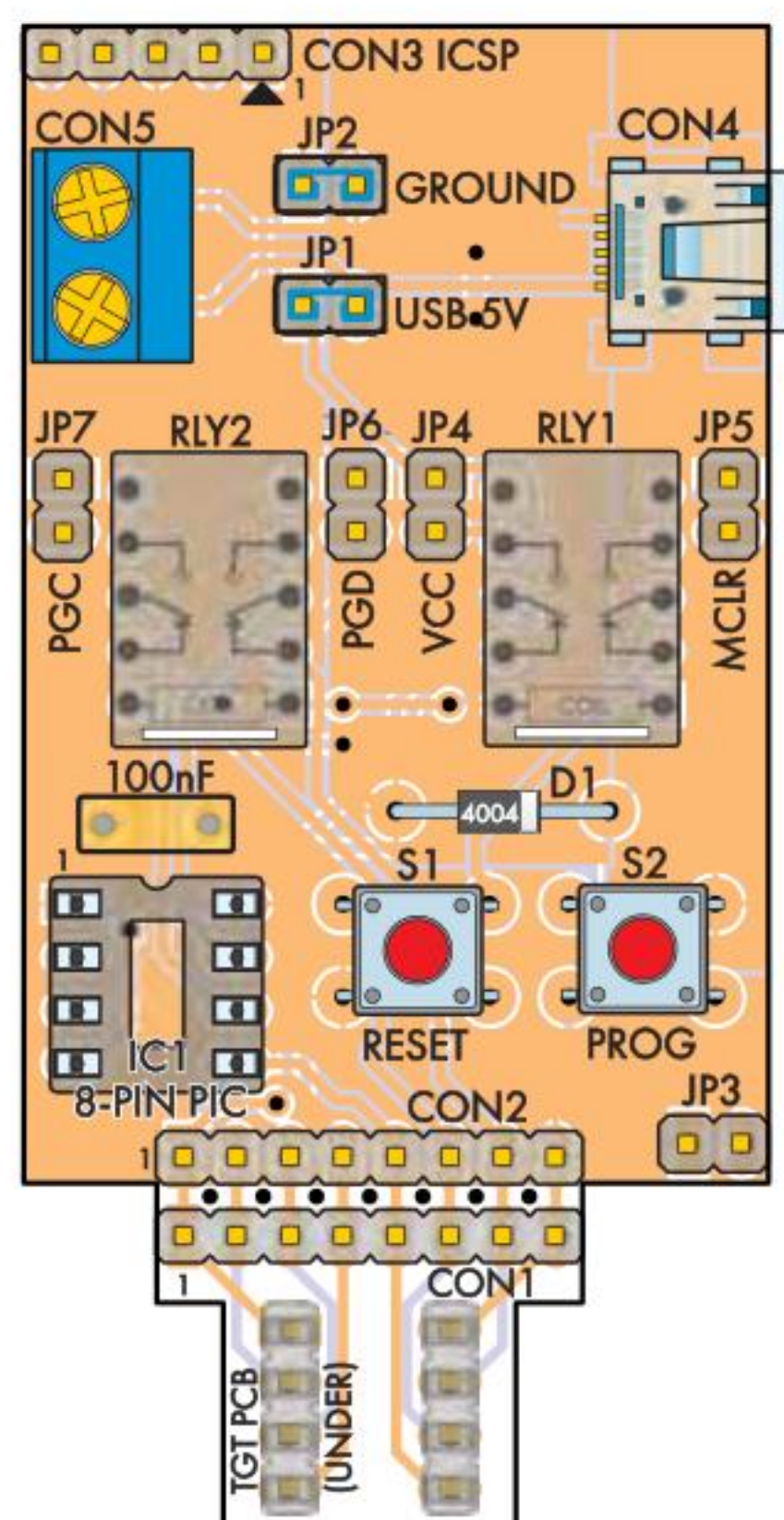


Fig.3: construction of this 8-pin version of the Helper is straightforward, but we recommend fitting a socket for IC1 so that you can change it out for different parts in the future. Also note that the pins fitted to the TGT pads should be installed underneath for the correct orientation when plugged in.

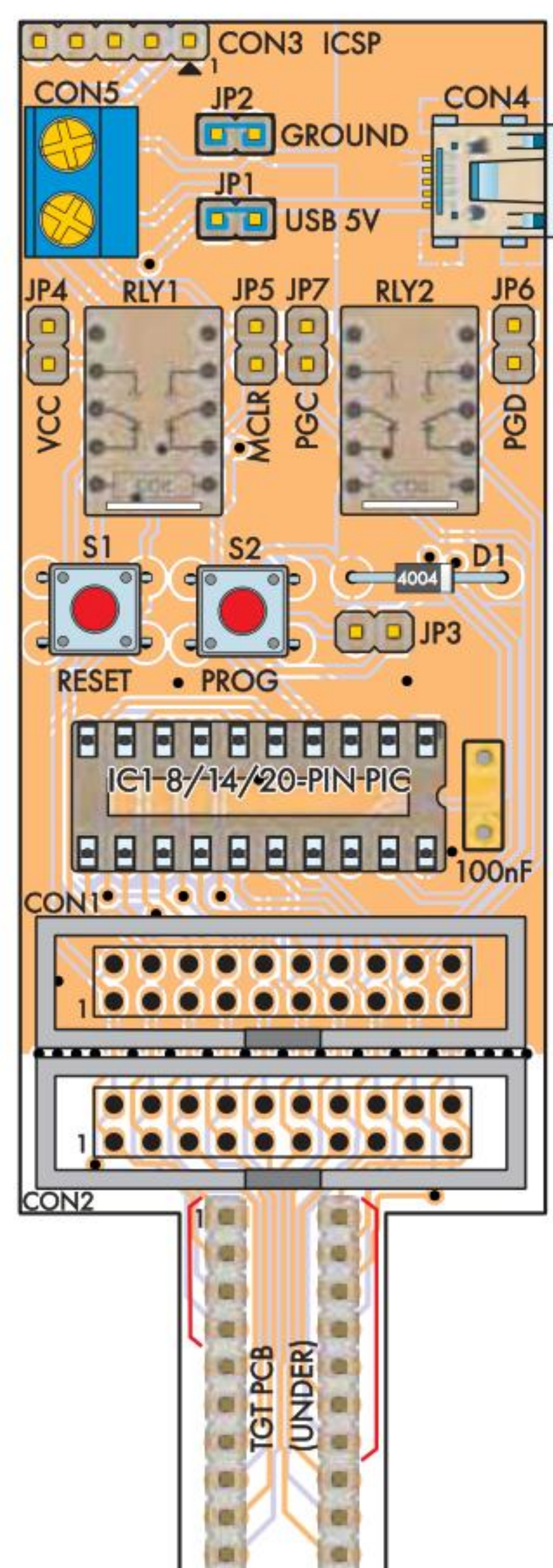


Fig.4: building this version that suits 8, 14 and 20-pin PICs is almost the same as the 8-pin only version. It just uses larger sockets for IC1 and the TGT connections, and larger headers for CON1 and CON2 (if fitted).

be easier to handle if fitted with the jumper shunt first, as it provides plastic surfaces that won't transfer heat as quickly. Solder these in the positions marked.

CON5 is intended to take a two-way screw terminal, but you could solder wires directly to the pads instead.

CON3 should ideally be a right-angled header to suit your programmer; our photos show the *PIC Programming Helper* connected to a low-cost Snap programmer, but the PICkit series is also suitable. You can temporarily fit the header to your programmer to ensure it is correctly aligned while soldering.

Next, fit buttons S1 and S2, pressing down firmly to snap them into place before soldering.

For the TGT PCB pad, we simply soldered header pins to the underside of the PCB. We aligned them by slotting them into an 8-pin DIL IC socket during soldering.

If you are using machined-pin IC sockets, you should solder machined pins to the *Helper*, or else they will not plug in properly. Test fit them before soldering to ensure that they will be held securely in the socket.

The advantage of using standard square header pins is that your prototype board (that the TGT PCB will plug into) could be fitted with socket strips during the testing phase, making plugging and unplugging this board very easy. They will also fit standard dual-wire sockets, although they are a tight fit.

Regardless, as you can see from our photos, these pins are fitted to the underside of the PCB to maintain the correct pinout.

If you have broken the PCB between CON1 and CON2, use a ribbon cable to bridge the gap. For the 8-pin version, simply wire pin 1 to pin 1 through to pin 8 to pin 8. You could also fit header pins to both ends and use jumper wires to join them.

For the 14-pin/20-pin version, you're better off fitting 2x10-pin headers to the boards at both ends, then using a length of 20-way ribbon cable fitted with IDC line sockets at either end. Make sure when you plug it in that the pin 1 stripe is at the pin 1 end of both headers.

Testing

Apply 5V power via CON4 or CON5 and press S2; you should hear the relays clicking. If you don't, then the relays or diode D1 might be reversed. You should get a similar result by shorting JP3.

Another simple test is to use any circuit that has a socketed 8-pin PIC (or

14-pin or 20-pin if you built the larger version). Remove the PIC from the socket and place it in IC1's socket, then fit the TGT PCB pins into the vacated socket. If all the pins are connected correctly, then the circuit should work as designed.

Usage

See the separate panel at right for information about how we modified our Snap programmer to provide 3.3V or 5V power to the target circuit. With this modification, we're able to use the much cheaper Snap in a wider variety of roles.

Since this modification provides adequate USB power when set to 5V, it can easily power the relays, and we don't need to supply any other power to the *PIC Programming Helper* – JP1 and JP2 just need to be shorted.

Other programmers (such as the PICkit 2, PICkit 3 or PICkit 4) can be used with this arrangement, although these programmers might only be able to source a limited amount of current. Our experience is that they can supply a fair bit beyond what a PIC needs, but if it is not sufficient, power the relays on the *PIC Programming Helper* via CON4 after removing shunts from JP1 and JP2.

In our setup, we've also fitted JP4 to provide 5V to the programming target. Our project is intended to be powered externally, but this means we don't have to make a separate power connection to our breadboard prototype.

Plug your development PIC into the onboard socket, then connect the TGT PCB header to your custom PCB's IC socket to complete the 'emulation'.

At this stage, the breadboard project is in normal operating mode and can be powered up. To reprogram IC1, press and hold S2 (or toggle a switch attached to JP3), then start the programming process. Once it is complete, release S2 (or re-toggle the switch across JP3).

If necessary, press S1 momentarily to reset your target PIC, and it will be back in the normal operating mode.

Summary

While we had a specific use case design in mind when designing this project, it is generally useful while working with most 8, 14 or 20-pin PIC microcontrollers.

The various jumpers provide the means to set up different combinations of connections, including powering it from various sources.

We hope the *PIC Programming Helper* will become as handy a tool in your development and prototyping toolkit, as it has for us.

Modifying the Snap programmer to provide power

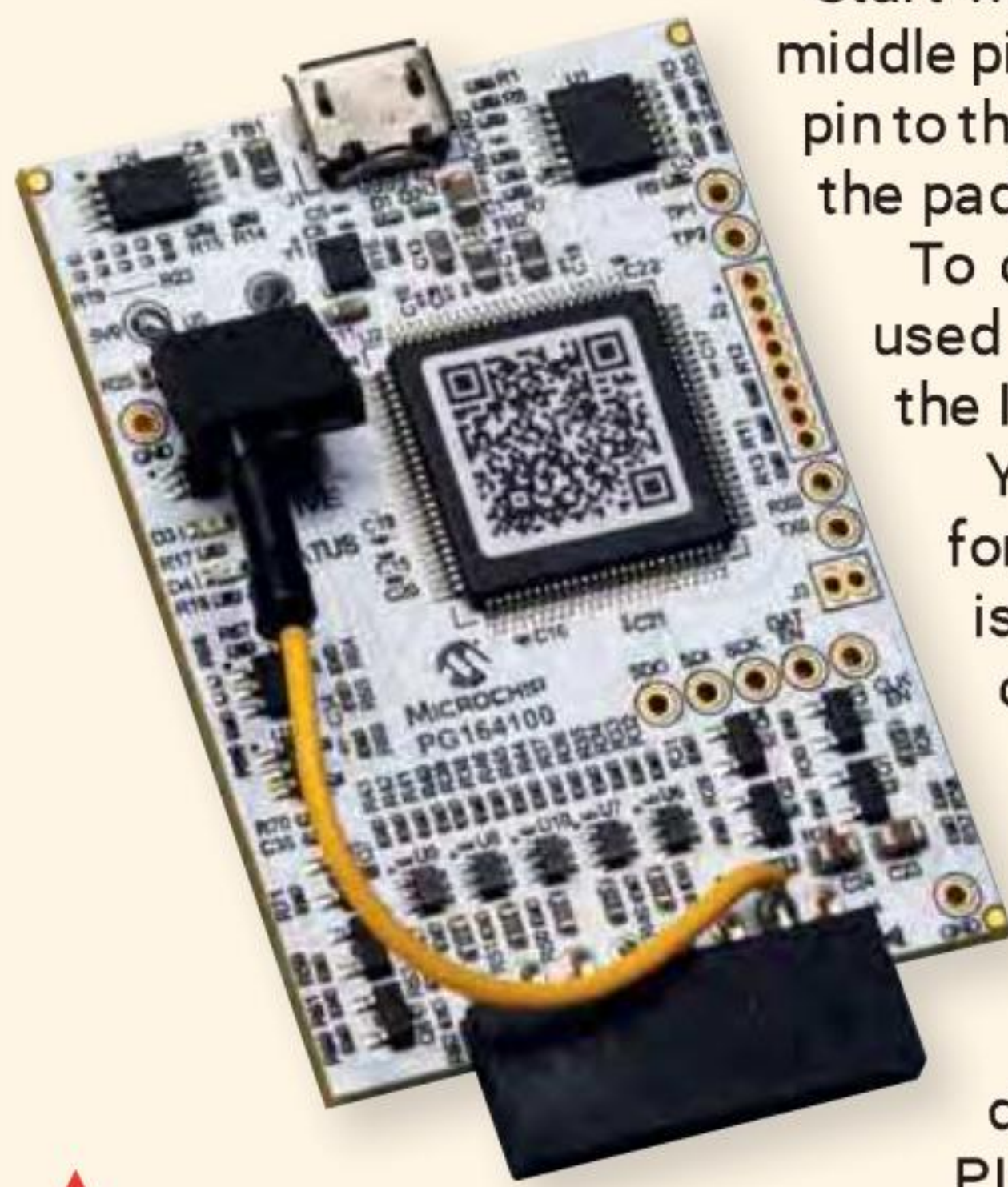
The Snap programmer is great value, packing many of the same features as the PICkit 4 for around a third of the price. But two features it lacks are the ability to provide power to a target chip, and providing the higher V_{PP} voltage needed to use high-voltage programming mode.

Luckily, the second aspect is becoming less important. Practically all newer PICs support low-voltage programming for most cases. Where the MCLR pin is not needed as an input, it's likely that high-voltage programming is not required, except for a few older PICs.

If we can use the Snap to provide power to its ICSP header, then it can come very close to supplanting the PICkit 4.

In a stroke of luck (or was it by design?), there are a pair of test pads on the Snap which provide both 5V and 3.3V power. These are located adjacent to U5, a 3.3V MCP1727 linear regulator capable of delivering up to 1.5A.

Our update is to solder a 3-pin socket header to these pins. They are spaced around 6mm apart, so this can be done reasonably elegantly with a 0.1-inch (2.54mm) pitch header simply using the outside pins. The photo below should make this fairly clear.



▲ The added header has been tilted to prevent it from being too bulky, and to allow the flying lead to enter at a comfortable angle.

Start with a 3-way female socket and trim the middle pin close to the plastic shroud. Solder one pin to the pad marked 5V0 and the second pin to the pad marked 3V3.

To connect power to the ICSP header, we used half a jumper wire soldered to pin 2 of the ICSP header.

You can plug this into the left-hand socket for 5V, the right-hand socket for 3.3V (which is necessary for most PIC32 parts) or the centre socket to provide no power. Just make sure that the shortened middle pin isn't contacting anything on the board.

With this simple addition, we are now using the Snap for practically all our development work. Note that it doesn't have the current limiting that a PICkit 4 would provide.

Parts List - PIC Programming Helper

- 1 double-sided PCB coded 24106211 measuring 37 x 72mm, for 8-pin PICs only, **OR**
- 1 double-sided PCB coded 24106212 measuring 37 x 105.5mm, for 8, 14 or 20-pin PICs (both PCBs are available from the PE PCB Service)
- 2 compact 5V DIL telecom relays (10-pin DIP, eg, TQ2-5V or EA2-5NU) 7 2-way male pin headers and jumper shunts (JP1-JP7)
- 2 4-way male pin headers **OR**
- 2 10-way male pin headers (to connect to TGT PCB; see text)
- 1 5-way male right-angle pin header (CON3, ICSP)
- 1 8-pin, 14-pin or 20-pin DIL socket (for IC1)
- 1 2-way mini screw terminal block (CON4)
- 1 mini Type-B USB socket (CON5)
- 1 1N4004 1A diode (D1)
- 2 tactile switches (S1, S2)

Optional parts to split 8-pin version

- 1 10cm length of 8-way ribbon cable

Optional parts to split 8/14/20-pin version

- 1 10cm length of 20-way ribbon cable
- 2 20-pin IDC line sockets
- 2 10x2 pin headers

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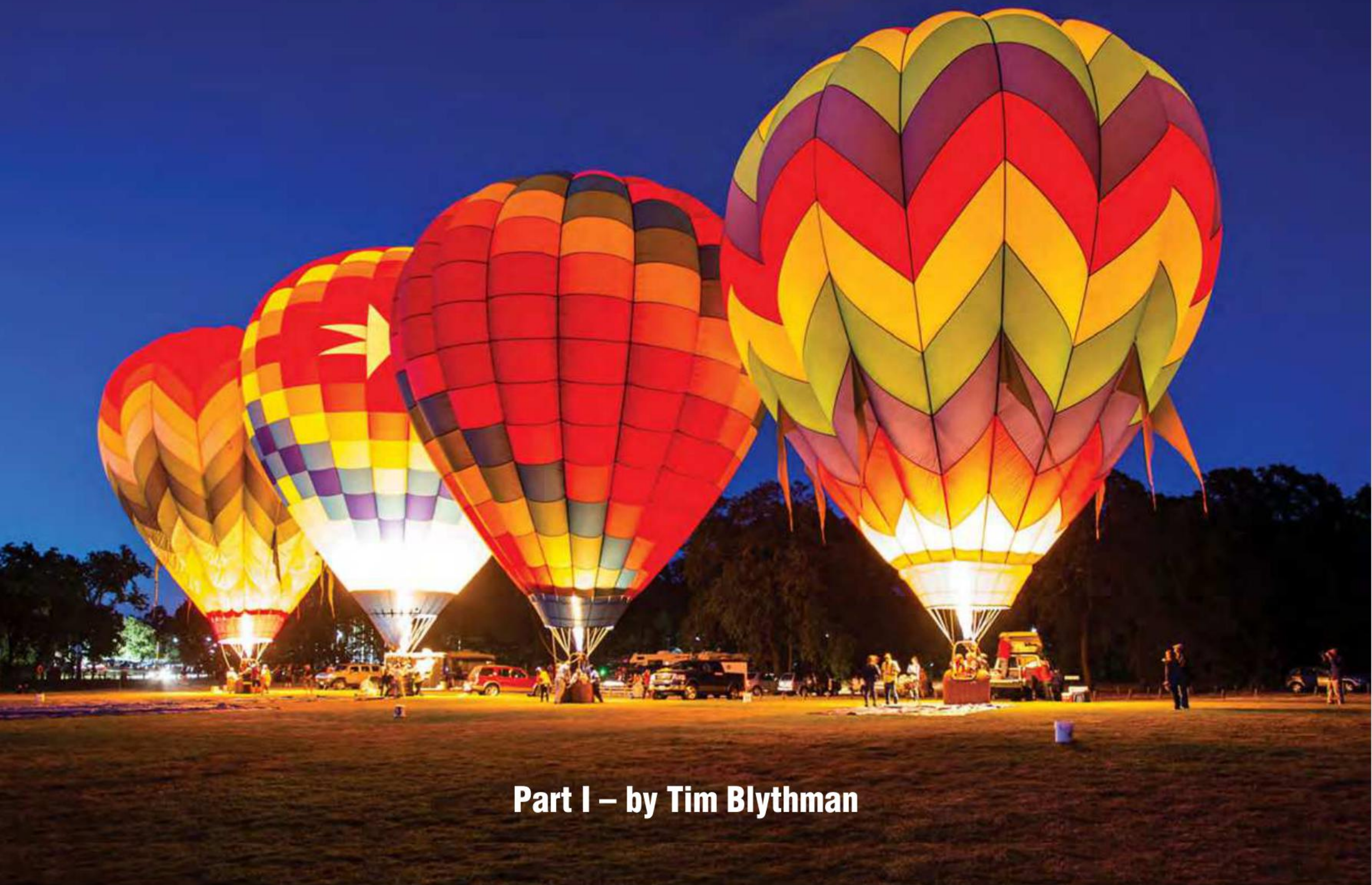
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Advanced GPS Computer



Part I – by Tim Blythman

What's your transport mode? Shanks' Pony? Car? RV? Boat? Plane? Hot Air Balloon? With a 3.5-inch touchscreen, our new *Advanced GPS Computer* is a great tool for on the road, in the water or even up in the sky. It can be customised to exactly how you want it. You'll wonder how you ever did without it!

The Touchscreen Boat Computer with GPS has been a phenomenally popular project.

Originally released five years ago (August 2017), it became one of the first projects to show just how handy and versatile the first *Micromite LCD Backpack* could be.

We've had numerous requests for features to be added – it was clear that people weren't just using it in their boats, but on the road, and even in the sky.

Suggestions included providing three simple screens for use on the road. One screen offering GPS ground speed and a compass display, while the others show

the time, date and satellite data. These examples also built in a speedometer and added automatic backlight control.

So, we thought, why not combine all these features (and more) into a newer and even better unit? It could use a larger 3.5-inch touchscreen to make the display more visible,

with software changes so that users could adjust the displays to their specific needs and liking.

While thinking about these improvements, we also decided to add a useful piece of functionality that takes advantage of the unit's ability to measure speed – an automatic volume controller.

Features and Specifications

- Based on Micromite LCD Backpack V3 with 3.5-inch LCD touchscreen
- Custom display and information screens including current and average speed along with time
- Powered by a rechargeable battery and/or DC supply
- Adds automatic volume control to vehicle entertainment systems
- Automatic backlight control
- Programmed in MMBasic
- Points of interest (POIs) can be saved and navigated to
- Internal speaker for warning announcements and tones



One of the frequently suggested improvements we had for our previous GPS design was that its display was too small. The Advanced GPS Computer offers a speed display which takes up most of the 3.5in LCD. And if you don't want a speed display, you can customise it to include a selection of other information.

The new GPS Computer

The *Advanced GPS Computer* is a culmination of all these features and advancements. Naturally, it incorporates the POI (Point Of Interest) feature from the *Boat Computer*. This allows GPS coordinates to be 'bookmarked'. The *GPS Computer* can then display the heading and distance to the POI, allowing simple navigation, or perhaps helping you to find that favourite fishing spot again.

It won't give you turn-by-turn navigation, but it can at least point you in the right direction.

A large speedometer display is also present, as are numerous other GPS and time-related data. These include

latitude, longitude, altitude, compass heading and the average speed.

Thanks to the handy automatic volume control mentioned above, you can feed audio through the device, via a 3.5mm stereo jack socket, and it will automatically adjust the volume according to your vehicle's speed. The output is louder at higher speeds, to help overcome increased noise from the vehicle. (See the box below for further details of the thinking behind this upgrade.)

Our revised design adds many more new functions. An audio synthesiser can inject warning sounds, alerts and even spoken words to the audio path, which can be

Why do you need to turn the volume up when you're moving faster?

Most sources of noise you hear in a vehicle vary depending upon your speed. The major sources vary from vehicle to vehicle, but it typically consists of a mix of road (tyre) noise, engine noise and wind noise. (Engine noise can be further broken up into induction noise, mechanical noise, transmission noise and exhaust noise.)

Road noise

Road noise is the sound that your tyres make as they rotate and distort under the weight of the vehicle. This varies based on speed, road surface, conditions (eg, water on the road) and tyre type/condition.

It's attenuated by the vehicle's soundproofing, but of course some vehicles have much better soundproofing than others.

The only easy way to reduce this is to swap out your tyres for quieter ones, but there is usually a compromise between quietness, grip and cost. So, if you

want quiet tyres with lots of grip, they will probably be costly. And high-performance tyres are usually noisy even though they are expensive.

Engine noise

The noise from an engine varies with many different parameters. There is little of this in an electric car – usually just a whine.

However, petrol and diesel engines can vary from whisper quiet to deafening. This varies to some extent based on load, which is related to how fast you are going, as well as whether you're going up or down a hill and whether you are accelerating, cruising or coasting.

Engine noise consists primarily of induction noise (air going into the engine) and mechanical noise (fuel injectors, valves, gears). Combustion noise is normally muffled significantly by the water jacket.

Vehicles with forced induction (turbo- or supercharged) typically have less induction noise, since the compressor muffles it.

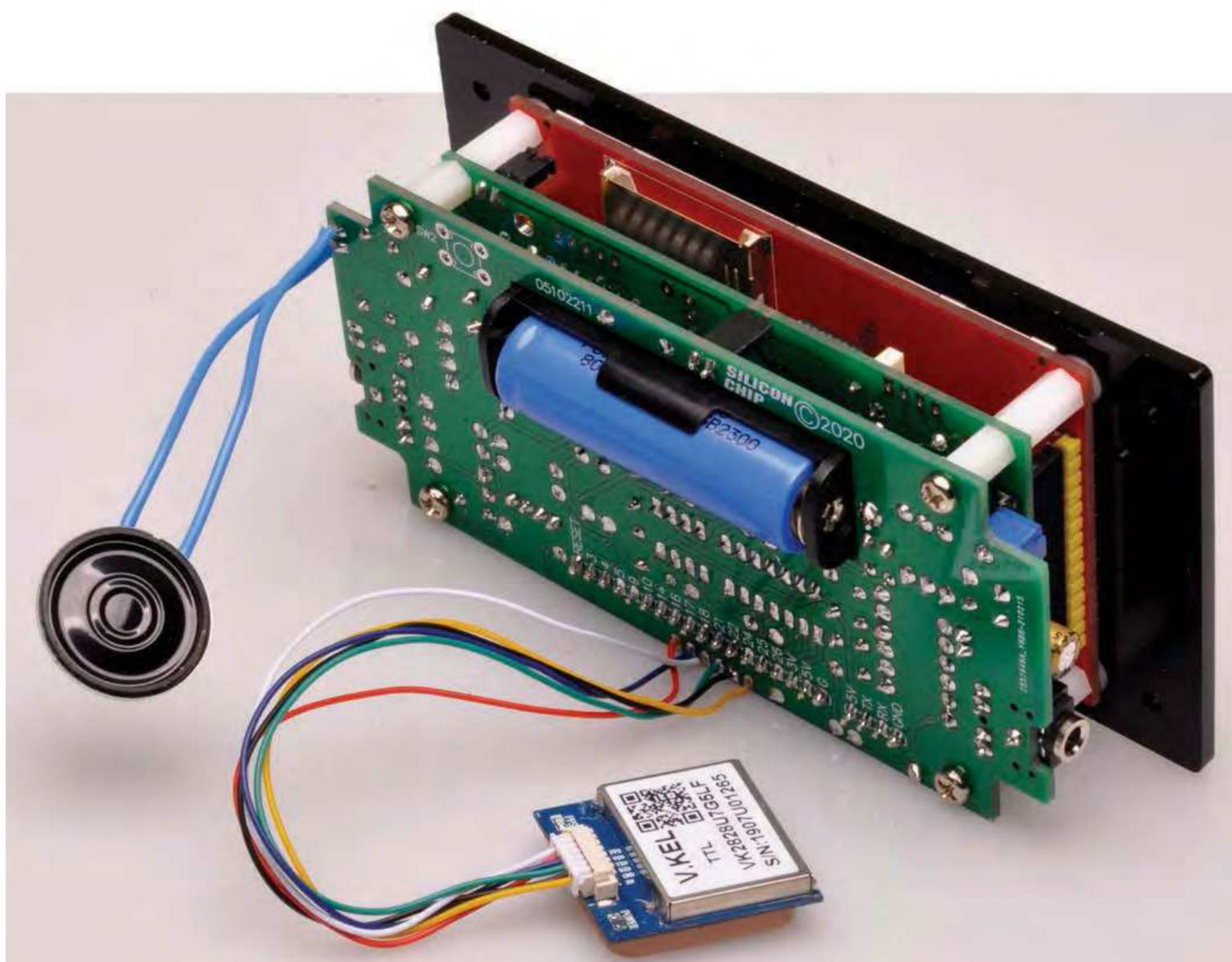
But modern direct-injection petrol or diesel engines typically have very audible injectors, while older engines may have more valve-train noise.

Exhaust noise depends on the type of engine, load conditions and exhaust system type and condition. Exhausts in poor condition or high-performance exhausts will let a lot more noise through. Turbocharged cars may have less exhaust noise since the turbine reduces exhaust pressure pulses.

Wind noise

You typically only hear wind noise at higher speeds and usually only if the other sources of noise are low (ie, a well-insulated car with a quiet engine cruising at speed). You may hear whistles or buffeting.

This varies depending on the aerodynamic design and anything attached to the outside of the vehicle, such as a roof rack, rain shields, bull bar and so on.



The Advanced GPS computer PCB fits to the rear of a stack consisting of a Micromite V3 Backpack and a 3.5-inch LCD. A tactile switch can be mounted to the rear at the pads labelled SW2 (S2) to allow operation from the rear of a UB3 Jiffy Box. Note that an integrated Li-ion battery and holder fit into a cutout within the rear PCB.

fed either to the 3.5mm output jack or a small onboard amplifier and speaker.

An RTC (real-time clock) IC provides accurate time-keeping, even if the GPS receiver has not locked onto enough satellites. A rechargeable battery provides an integrated power supply. The battery state is displayed onscreen, and the unit allows low-power sleep operation, which keeps the GPS active as well as a complete power-off mode.

But we think that the most important new feature is the high degree of customisation that is possible. Four user-customisable displays are available that can be changed to show various parameters in different units. The displayed screens are also fully customisable to show exactly the combination of information that you want. Since the user interface is written in MMBasic, it can be further tweaked by advanced users, as and when needed.

Hardware

Our photos show the main electronics for the GPS Computer consisting of three boards sandwiched together. This stack fits neatly into a plastic UB3 Jiffy box. The top two boards will be familiar to readers as the *Micromite V3 Backpack* and its accompanying 3.5in LCD touchscreen. If you aren't familiar with that device, we recommend reading the article describing it in the August 2020 issue.

The *Micromite V3 Backpack* used here is close to its minimum configuration. JP1 is fitted so it will draw power from its USB socket, and it is set up for pulse-width modulation (PWM) backlight control. This is necessary to allow for automatic backlight adjustment.

The only optional parts fitted to the *Micromite V3 Backpack* board are to enable the RTC feature, and include the DS3231 clock IC and its accompanying passives; two 4.7k Ω I²C pull-up resistors and a 100nF bypass capacitor. Also, a two-pin header is fitted to the *BackPack*'s CON9 to supply power to the battery input of the RTC IC.

The other optional parts supported by the *Micromite V3 Backpack* should not be fitted as they might conflict with some pin assignments. In particular, the parts in the Flash IC box must not be fitted, nor should the IR receiver. The latter won't cause a conflict, but the receiver is unusable from within MMBasic when programmed with this project's software.

Add-on PCB

The third board in the stack mentioned earlier is the custom add-board for this project. It just plugs into the *Micromite V3 Backpack*, and the circuit for this board is shown in Fig.1.

Connection to the *BackPack* is via three headers. The 18-way and four-way headers provide connections for the Micromite's I/O and power pins, as for most Micromite

Fig.1 (opposite): the Micromite V3 Backpack PCB includes the USB data interface, a 32-bit microcontroller, the touchscreen interface and a DS3231 real-time clock IC. The remaining functions are on the GPS Computer PCB, the circuit of which is shown here. It primarily has a GPS module for speed, time and location data, a digital pot for volume control, op amps for signal conditioning, a power amplifier to drive the small speaker for warning sounds, plus a Li-ion battery charger that runs from 5V.

floating when nothing is connected, after which it passes through a 1k Ω series resistor. This protects against high currents flowing into the device, and blocks RF signals that the external wiring might pick up.

The signal is AC-coupled by a 1 μ F ceramic capacitor and biased (via a 22k Ω resistor) to a 2.5V mid-rail. This rail is generated by a pair of 10k Ω resistors across the 5V supply, bypassed by a 220 μ F capacitor to eliminate supply noise.

IC1 is an MCP4251 5k Ω dual gang digital potentiometer with 257 steps. The 'lower' end of the track (pin 10 for the left channel or pin 5 for the right channel) is tied to the 2.5V rail, while the other ends are connected to the conditioned audio signals (pin 8 for the left channel, and pin 7 for the right).

The 5k Ω resistance in series with the 1k Ω input resistance and the biasing components means that the signals at pins 7 and 8 are around 80% of the initial magnitude.

The signals on the potentiometer 'wipers', pins 9 (left) and 6 (right), are attenuated depending on the internal potentiometer setting. This is controlled by an SPI serial bus on pins 1 ($\overline{CS}$), 2 (SCK) and 3 (SDI) of IC1. The bus is driven from pins 10, 25 and 3 of the Micromite respectively, via the 18-way I/O header.

Note that the MCP4251 is designed to accept different analogue and digital voltage levels. So it will happily accept the 3.3V digital control signals from the Micromite alongside the 5V maximum audio signals and digital supply voltage.

Dual-channel rail-to-rail op amp IC2 is set up to provide a gain of about three times, both to improve the output drive level and expand the volume range. Thus, the full-scale

output corresponds to around 240% of the incoming signal; close to 1% per potentiometer step.

A rail-to-rail op amp is needed here due to the narrow supply range. We've specified an LMC6482, but other similar rail-to-rail devices like the MCP6272 should work fine. Both IC1 and IC2 have their supplies bypassed with 100nF capacitors.

The volume-adjusted audio is fed into non-inverting input pins 3 and 5 (left and right) of IC2, with a 10k Ω /5.1k Ω divider connected between the output pins (1 for left and 7 for right) and inverting input pins (2 for left and 6 for right). These dividers set the gains to around three times.

The output signals are AC-coupled and passed through 100 Ω resistors to ensure stability and to protect the op amp outputs, then biased to ground via 22k Ω resistors and made available at CON2, the 3.5mm output socket.

Signal injection

Another signal can be injected into the audio path from the Micromite's pin 24, which is PWM-capable and thus can generate tones or PWM-synthesised analogue signals.

The signal from pin 24 is fed into VR1 to provide level control. VR1, the 470 Ω series resistor and 10nF capacitor form a low-pass filter to remove any supersonic artefacts from PWM analogue signal synthesis.

At this point, there are two options for where this synthesised audio signal can go.

With two jumpers on each of JP1/JP2 (across positions 1 and 2, and positions 3 and 4), the 2.2k Ω resistors and 1 μ F capacitors AC-couple this signal into the left and right channels of the existing stereo path, just before they are fed into IC1. This has the advantage that the warning

sounds will be heard through your vehicle speakers. The disadvantage is that these components introduce a small amount of cross-talk between the channels, reducing stereo separation slightly.

In this mode, the jumpers on positions 3 and 4 feed the audio from the op amp outputs to a pair of mixer resistors and then into inverting input pin 4 of SSM2211 audio amplifier IC3. Its non-inverting pin (pin 3) is tied to pin 2, which outputs a mid-rail bias voltage and is bypassed by a 100nF capacitor. A second 100nF capacitor provides supply bypassing between, pins 6 and 7.

IC3's SHDN pin 1 is held low to enable the amplifier. The output signal from pin 5 is fed back to pin 4 via a 22k Ω resistor, giving close to unity gain, as the two 47k Ω input resistors are effectively in parallel. A speaker connected at CON3 is driven by the push-pull signal from pin 5 and pin 8 of IC3.

The unity-gain setting means that (as much as possible) the full 5V headroom is available to both the op amp and amplifier. IC3 is capable of delivering around 1W into 8 Ω or up to 1.5W into 4 Ω .

The alternative configuration is to have a single jumper on both JP1 and JP2, between positions 2 and 3. This keeps the 3.5mm audio path separate from the synthesised audio, and only the synthesised audio is fed to the speaker connected to CON3.

Battery circuitry

A small Li-ion cell is connected to the circuit at the BAT+ and BAT- terminals. A slot in the PCB provides space for a 14500-size cell (roughly the same as AA cells). The cell can be connected via a PCB-mounting cell holder; or alternatively, you



Many readers have made their own tweaks to the various screens used by the older Micromite Boat Computer. This new GPS Computer allows custom screens to be laid out without having to delve into the MMBasic code. At left, we see the screen that allows various tiles to be placed, while at right, the screen is seen in use, containing exactly the information that is needed.

could solder the cell's tabs directly to the PCB.

It provides power to the real-time clock IC on the Backpack via D2 and CON4. The diode drops the voltage slightly from the 4.2V that a fully-charged Li-ion cell delivers, reducing the quiescent current slightly. The diode also prevents power from being fed back into the cell.

The cell is charged from 5V USB power when available. IC4 is an MCP73831 battery charging IC (in a small SOT-23-5 SMD package). The 4.7µF supply bypass capacitor between pins 4 (VIN) and 2 (ground) is as specified in the data sheet, while the 10kΩ resistor between pin 5 (PROG) and ground sets the charge current to a nominal 100mA.

The cell and another 4.7µF capacitor are connected between pin 3 (BATTERY) and ground. Pin 1 (STAT) is driven low during charging and high when the charging has been completed. This is displayed on bi-colour LED1, with one lead connected to the STAT pin and the other to the midpoint of a 1kΩ/1kΩ divider between 5V and ground.

When STAT is low, the red LED illuminates with current flowing via the upper resistor. The green LED illuminates when charging completes, STAT goes high and current flows through the lower resistor. With 5V power absent, the LED is off, and no current flows through the divider.

Schottky diode D1 feeds the battery voltage into the rest of the circuit, and is forward-biased when the circuit is drawing current from the cell. The diode is included to prevent the 5V supply from being backed directly into the cell when powered externally.

High-side P-channel MOSFET Q1 switches battery power to the majority of the circuit, but is usually held off by the 1kΩ resistor between its source and gate. The gate can be pulled low by switches S1 or S2, or N-channel MOSFET Q2. When the gate is pulled down, the battery supplies power to the circuit.

MOSFET Q2 is similarly held off by the 10kΩ resistor on its gate, and can be turned on by Micromite pin 9 going high.

S1 is simply a two-pin header to which any momentary switch can be wired, while S2 is a PCB footprint suiting a tactile switch; in effect, they (and Q2's drain and source) are simply connected in parallel.

Typical operation is as follows. When USB power is applied, the Micromite starts up and runs its program. One of the first things it does is

Parts list – Advanced GPS Computer

- 1 Micromite LCD Backpack V3 with DS3231 RTC (see below); PCB available from the PE PCB Service (August 2020)
- 1 double-sided PCB coded 05102211, 123x58mm, available from the PE PCB Service
- 1 UB3 Jiffy box
- 1 laser-cut acrylic panel to suit (Cat SC5856)
- 1 VK2828U7G5LF or similar GPS module (GPS1) [Cat SC3362]
- 1 PCB-mount AA cell holder (for BAT1)
- 1 14500 Li-ion cell with nipple (BAT1)
- 2 PCB-mount switched stereo 3.5mm sockets (CON1, CON2) [eg, Altronics P0094]
- 1 small, slim 4-8Ω 1W speaker [eg, Digi-Key 2104-SM230808-1]
- 1 100kΩ-10MΩ LDR (LDR1) [ORP12 or equivalent; eg, Jaycar RD3480]
- 1 tactile switch (S1/S2) [see text for overall height considerations and alternatives]
- 1 2-pin male header (CON4)
- 1 18-pin male header (CON5)
- 3 4-pin male headers (CON6, JP1, JP2)
- 4 jumper shunts (JP1, JP2)
- 4 M3 x 15mm panhead machine screws
- 4 M3 x 10mm panhead machine screws
- 4 M3 x 12mm tapped spacers
- 4 M3 x 10mm tapped or untapped spacers
- 4 M3 Nylon washers
- 1 10cm length of 1.5mm diameter heatshrink tubing
- 1 10cm length of light-duty hookup wire (for the speaker)

Semiconductors

- 1 MCP4251-502E/P dual 5kΩ digital potentiometer, DIP-14 (IC1)
- 1 LMC6482AIN dual rail-to-rail op amp, DIP-8 (IC2) [MCP6272 is a substitute]
- 1 SSM2211SZ push-pull 1.5W amplifier, SOIC-8 (IC3) [Digi-Key, Mouser, RS]
- 1 MCP73831T-2ACI/OT Li-ion battery charger, SOT-23-5 (IC4) [Digi-Key, Mouser, RS]
- 1 3mm bi-colour (2-wire) red/green LED (LED1)
- 1 1N5819 1A schottky diode (D1)
- 1 1N4148 small signal diode (D2)
- 1 IRLML2244 P-channel MOSFET, SOT-23 (Q1)
- 1 2N7002 N-channel MOSFET, SOT-23 (Q2)

Capacitors

- 1 220µF 16V electrolytic
- 2 4.7µF 16V multi-layer ceramic [eg, RCER71H475K3K1H03B from Digi-Key, Mouser or RS]
- 6 1µF 50V multi-layer ceramic [eg, Jaycar RC5499]
- 5 100nF 63V/100V MKT (Code 104 or 100n)
- 1 10nF 63V/100V MKT (Code 103 or 10n)

Resistors (all 1/4W axial 1% metal film)

- 1 1MΩ
- 2 100kΩ
- 2 47kΩ
- 5 22kΩ
- 6 10kΩ
- 2 5.1kΩ
- 2 2.2kΩ
- 5 1kΩ
- 1 470Ω
- 2 100Ω
- 1 1kΩ mini horizontal trimpot (Code 102)

Additional parts for V3 Backpack PCB (visit micromite.org for Micromite parts)

- 1 DS3231 real-time IC, SOIC-16 (IC4) [Cat SC5103]
- 1 2-pin female header socket (CON9)
- 1 18-pin female header socket (for Micromite I/O)
- 1 4-pin female header socket (for Micromite power)
- 1 100nF MKT capacitor
- 2 4.7kΩ 1% 1/4W axial resistors

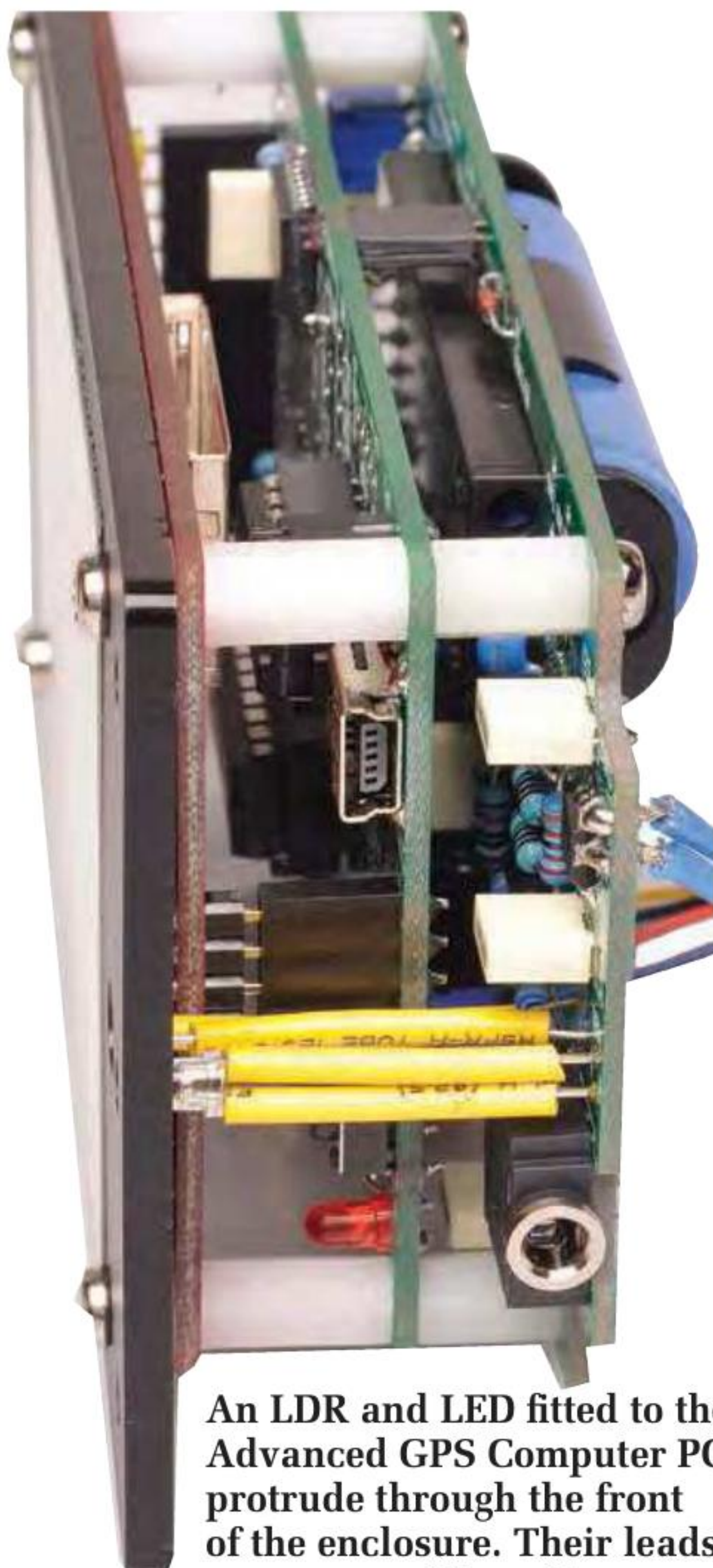
Software: The firmware package for the Advanced GPS Computer, including the MMBasic source code, HEX file to program the chip, the CFUNCTIONs and some of the programs that were used to generate the graphics will be available with the next issue.

pull pin 9 high, so that Q2 conducts and thus Q1 is switched on. This means that if USB power is removed, the Micromite will continue to run from the battery.

If the Micromite wishes to shut down and stop running from the

battery (either due to the battery being depleted or a user request), it pulls pin 9 low, shutting off Q1 and disconnecting its own supply.

If the user wishes to start up the Micromite from battery power, they simply press S1 or S2 for a second,



An LDR and LED fitted to the Advanced GPS Computer PCB protrude through the front of the enclosure. Their leads are protected by yellow heatshrink. This view also shows how the battery holder is recessed.

turning on Q1 and allowing the Micromite to start up. It then sets pin 9 high which latches Q1, allowing the switch to be released.

Sensing

A handful of other components are provided to sense some other parameters. LDR1 and a 1MΩ resistor form a divider with an output voltage related to the current ambient light intensity. This is filtered by a 100nF capacitor, to avoid sudden changes, and is read

by the ADC (analogue-to-digital converter) peripheral on the Micromite's pin 4. The software uses the resulting value to modulate the brightness of the LCD backlight.

With a nominal LDR resistance between 100kΩ and 10MΩ, the measured voltage spans around 0.3V to 3V. It is mapped to brightness levels selected by the user. The backlight brightness is controlled by a PWM signal from the Micromite's pin 26 and effected by components on the V3 Backpack board.

The supply voltage is also monitored, by reading the voltage on the audio circuit's mid-rail divider, via pin 5. The measured battery divider voltage is doubled in software to get its actual value. Two thresholds are used to determine the GPS Computer's power state – the upper level discriminates between the 5V delivered by USB power, and the 4.3V of a fully-charged cell.

A second threshold is used to determine a lower limit for the battery, to allow the Micromite to shut down before the battery is discharged excessively. Between these thresholds, a rough state-of-charge figure is calculated and is displayed when running from battery power.

The Micromite's pins 4 and 5 are also used for in-circuit programming, which means the *GPS Computer* PCB must be disconnected if the chip needs to be reprogrammed.

The optional Flash IC that can be installed on the V3 Backpack uses pin 4 too; thus, it also would conflict with the *GPS Computer's* operation.

The 3.3V reference for the Micromite's ADC depends strongly on having an accurate 3.3V supply voltage because the calculated pin voltage is based on an assumed 3.3V supply. With a 5V USB supply, the 3.3V

regulator has no trouble maintaining this value.

When running from battery power, the Li-ion cell is not allowed to discharge below about 3.6V. Otherwise, the Micromite chip's supply can drop below 3.3V (dropping about 0.2V due to D1 and another 0.2V in the regulator), which would affect ADC readings. (Note that this is also why LiFePO₄ cells are not suitable for this design, as their normal operating voltage is below 3.6V.)

GPS receiver

Of course, it wouldn't be a GPS computer without being able to receive a GPS signal. Six-way header GPS1 allows a GPS module, such as the VK2828 type, to be attached. The header provides power and routes the GPS serial data back to the Micromite's COM1 RX at pin 22.

Power is supplied to the GPS module from the battery downstream of D1, allowing the 5V supply to preferentially feed the GPS module when available (via Q1).

If this were not done, the GPS module would draw current from the battery even when USB power was available, and the charging circuit would not detect that charging is complete.

The GPS module's EN pin is connected to the nominal 5V rail, allowing the GPS module to go into low-power mode when the *GPS Computer* switches off (either USB power is unavailable or Q1 is off). This allows the GPS module to retain satellite information when the *GPS Computer* is off, allowing faster satellite acquisition when needed.

While the VK2828 datasheet indicates a 40μA power-down current, we measured around 2mA being consumed by the module. However, removing the POWER LED on the GPS



There are a total of 23 different tiles that can be placed, including numerous parameters drawn from the GPS data and related to selected POIs (points of interest). A number of tiles appear as buttons, adding further functions to a screen, such as being able to quickly access a different screen.



One tile which we are sure will be popular is a simple, clear, large, easy-to-read speed readout. The units can be changed between many common road, nautical and aeronautical formats. There's even enough room left over to add a handful of other tiles below this.

module saw this fall to the expected value.

Software operation

The photos of the *GPS Computer* that we’ve presented should give you a good idea of its capabilities; there isn’t much mystery as to how it achieves what it does. The Micromite receives GPS data from the GPS module and displays it on the LCD screen.

Of course, there is quite a bit more going on than that suggests. We wouldn’t be surprised if readers find some interesting ways to use the software we’ve written.

CFUNCTIONS

Micromite’s MMBasic is very powerful, but it isn’t especially fast. Fortunately, there is the option to incorporate so-called CSUBs and CFUNCTIONs into a program.

These are effectively precompiled machine-code routines that can run without the MMBasic interpreter’s overhead, but can be invoked from the MMBasic code. We use the CSUBs and CFUNCTIONs for three broad roles.

The first is controlling the 3.5-inch LCD panel. There is no native driver for the ILI9488 display controller on the 3.5-inch panel, and it would be far to slow to do this in MMBasic. We’ve used this code previously in the *RCL Substitution Box* from June and July 2021.

The two other functions are diverse, but are combined into another CFUNCTION specifically for the GPS Computer. One handles audio synthesis, while the other processes data from the GPS receiver.

Audio production

While it is easy to create rough square-wave tones using a PWM output, they sound harsh. So we’ve written code that can play back PCM-coded audio samples. It’s limited to 8-bit data at 8kHz, as that is a reasonable compromise between the amount of space needed to store the samples and sound quality.

The PIC32MX170’s TIMER1 is pressed into service as the 8kHz sampling timer. Since the IR receiver function on the Micromite also depends on TIMER1, these functions cannot be used at the same time; hence, our comment earlier that there is no point fitting the IR receiver.

Pin 24 is set up to output the 8-bit PWM signal on a 156kHz carrier. With 256 levels, 156kHz is the highest PWM frequency available with a 40MHz processor clock. The RC filter noted earlier removes the 156kHz carrier, leaving just the audio frequency components.

Prefix	System
\$GP	GPS (USA)
\$GA	Galileo (Europe)
\$GL	GLONASS (Russia)
\$GB	Beidou (China)
\$GN	Combined data from more than one GNSS

Table 1: GNSS prefixes

When stored in memory, each audio sample data set is preceded by a 32-bit number indicating its length. During playback, the timer interrupt steps through the data until it reaches the end, after which it shuts down the PWM signal.

A software flag can cause the sample to loop, allowing sounds to be compactly stored as just one cycle in memory. For example, a 400Hz sine-wave cycle can be stored as 20 samples if the sampling rate is 8kHz.

With the PIC32’s flat 32-bit address space, these can be stored in Flash memory (program storage) or RAM (eg, variables). So the MMBasic code can create samples at runtime, then play them back.

There is also a facility to produce synthesised vocal effects using so-called ‘Linear Predictive Coding’ compression. LPC is a very efficient compression method for reproducing the human voice. It’s what was used in many talking toys from the early 1980s, such as the Texas Instruments Speak & Spell.

The compression is remarkable, needing fewer than 200 bytes per second. While Texas Instruments produced custom ICs to convert this to speech, it’s now possible to do this in software.

The easiest method is to use the open-source Arduino ‘Talkie’ library, which can be found at: <https://github.com/ArminJo/Talkie>

This allows an Arduino Uno (and other similar boards) to process LPC data into audio. That page also has links describing how the LPC data is stored and decoded.

We’ve included this functionality in the CFUNCTION to process LPC data to generate synthesised speech. Like any data that has been heavily compressed and output at a low sample rate, the sound is not great. But it’s recognisable and makes for a very intuitive interface.

So the *GPS Computer* can deliver either sampled audio or synthesised speech, although not at the same time, since they are output on the same pin.

GPS CFUNCTION

Our CFUNCTION also contains routines to help process the NMEA-formatted data from the GPS module. While MMBasic is quite capable

of performing this task, the CFUNCTION speeds this up considerably, leaving more time for other tasks.

The GPS data stream consists of a series of ‘sentences’ which contain a variety of data.

You can read more about their structure and content on page 19 in our April 2019 *Clayton’s GPS* project.

Our code defines several parsers, each corresponding to a sentence type, which is recognised from its prefix. Each parser then processes the data into an MMBasic string array if it is valid and correct, and sets a flag to let the main program know that new data is available.

We’ve also created some routines to decode the curious latitude and longitude formats used in NMEA data. One routine extracts the number of degrees, another the number of minutes and a third, the fractional number of seconds.

With several different satellite navigation systems coming online to complement GPS, we’re also seeing variations in the data that receivers produce. Such systems include the Russian GLONASS and Chinese Beidou systems.

For example, some receivers now generate sentence prefixes of ‘\$GN’ instead of ‘\$GP’, even though the data is otherwise identical. This simply reflects that the receiver is using a different satellite system to calculate its position. The various strings generated by different types of receivers are shown in Table 1 above.

But since it is only the third character of these sentences that changes, we simply ignore it instead of checking it, allowing the unit to process data from any receiver which outputs a similar format.

Part 2 next month

In the next issue, we’ll describe construction of the *Advanced GPS Computer* PCB, modification of the *Micromite V3 Backpack* to add a realtime clock IC, loading of software and how to assemble the parts into a completed unit.

Since we expect some people to be interested in making their own changes to the software, as they did with the previous *GPS Computer*, we’ll also delve deeper into how various parts of the software work.

You might even be curious about using the various CFUNCTIONs in your own projects.

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Max's Cool Beans

By Max the Magnificent



Flashing LEDs and drooling engineers – Part 28

As you may recall, in a previous column (*PE*, May 2022) I made mention of a modern incarnation of an analogue computer called *The Analog Thing (THAT)* (<https://bit.ly/370WEZH>). While mulling over this fascinating device, I was reminded of some nuggets of knowledge and tidbits of trivia that I wanted to share with someone, and it looks like you aren't in any position to get away, so...

When analogue ruled and digital drooled

Way back in the mists of time, the first true electronic systems were created using vacuum tubes ('valves' in the British vernacular and 'tubes' in North American parlance). These little rascals could act like diodes or switches or amplifiers. Early tube-based systems, like 1920s radios, were analogue in nature.

I have the greatest respect for the people who used to conceive and realise the most amazing analogue systems, often with naught more than a couple of tubes and a handful of resistors, capacitors and inductors. As I've mentioned on many an occasion, I'm a digital design engineer by trade and I find the wibbly-wobbly nature of analogue systems to be disquieting. In the case of even the simplest tube-based system, I can peruse and ponder its schematic diagram for hours without having a clue as to its purpose in life or the way in which it was intended to perform its magic. By comparison, any of my chums at the Alabama Historical Radio Society (ALHRS.org) could glance at the self-same schematic and then discourse for hours on the topic of, 'flobulating retrograde inductive couplings titivating the phase-change modulation' (or words to that effect).

The thing about analogue signal processing (ASP) is that you can do a tremendous amount of stuff with very little stuff, if you see what I mean. For example, adding two sine waves while filtering out any high-frequency noise is 'easy peasy lemon squeezy' using analogue techniques. By comparison, implementing the same functionality using digital signal processing (DSP) requires you to develop an appropriate algorithm and

tends to require an overly enthusiastic quantity of digital logic gates and registers, thereby leaving you 'stressed depressed lemon zest,' as it were.

On the other hand, as we've previously discussed, there are several issues with analogue systems, not least that – in the case of computers – you rarely get the same answer twice (there's always some difference, no matter how small). Another aspect of analogue is the way in which it tends to degrade information. In the days of video tapes, for example, if you took a video of grandma's birthday, and you made a copy for your aunt, and she made a copy for her friend, and... it wasn't long before the downstream copies became unwatchable. By comparison, when performing processing using digital techniques, you always get the same answer (unless you've messed something up), which I find to be comforting. Even better, the use of error checking and correction (ECC) codes makes it possible to make copies of copies of copies, with the last being identical to the first (hurray!). But we digress...

The rise of digital

Early digital computers, circa the beginning of the 1940s, were typically electromechanical (using relays) and/or electronic (using tubes). Most of these machines worked in decimal (base-10) and operated only on integers. Interestingly, a German engineer called Konrad Zuse had a fully mechanical, binary, floating-point computer called the Z1 up and running in 1938, but that's a story for another day.

Not surprisingly, machines based on these antediluvian technologies were fulsome in size and greedy for power. As I wrote in *Bebop Bytes Back* (<https://amzn.to/3MdgfFh>), the *Harvard Mark I*, which was developed in America between 1939 and 1944, was constructed out of switches, relays, rotating shafts, and clutches, and was described as sounding like 'a roomful of ladies knitting.' This machine contained more than 750,000 components, was 50-feet (15m) long, 8-feet (2.5m) tall, and weighed approximately five tons! Similarly, the *Electronic Numerical Integrator and Computer*

(*ENIAC*), which was constructed at the University of Pennsylvania between 1943 and 1946, was 10-feet (3m) tall, occupied 1,000 square feet (90m²) of floor-space, weighed in at approximately 30 tons, and used more than 70,000 resistors, 10,000 capacitors, 6,000 switches and 18,000 vacuum tubes. The final machine required 150kW of power, which was enough to light a small town at that time.

One of the greatest problems with computers built from vacuum tubes was reliability. For example, 90% of ENIAC's down-time was attributed to locating and replacing burnt-out tubes. Records from 1952 show that approximately 19,000 vacuum tubes had to be replaced in that year alone, which averages out to about 50 tubes a day!

Another consideration was that engineers who were conversant with the continuous nature of the analogue world could often handle the concept of asynchronous digital logic, but they found it difficult to comprehend the nuances of synchronous (clocked) digital systems. Things weren't helped by the fact that digital techniques themselves were not well understood at that time.

Life for computer pioneers started to get easier with the invention of semiconductor diodes and transistors, and even easier with the invention of integrated circuits. It also didn't hurt that we gained a better understanding of digital logic and its wily ways. Once we started building semiconductor-based processors, things like DSP really started to take off. These days, we can build chips with hundreds of millions of transistors (some have billions, a few have trillions), which explains why we now do so much processing using digital techniques.

Change is scary

On my meandering journey through life, I've met engineers who had black belts in designing with vacuum tubes, but who couldn't wrap their brains around using semiconductor devices like discrete (individually packaged) transistors.

I've also come into contact with analogue designers who could happily create masterpieces using discrete transistors, resistors and capacitors, but who couldn't

grasp the concept of digital functions like the primitive logic gates (NOT, AND, OR, NAND, NOR...) and register elements (latches, flip-flops...) provided in jellybean integrated circuits (ICs) such as the Texas Instruments 7400-series chips.

Even today, I know some digital engineers who are as happy as clams creating assembly language programs to run bare metal on 8-bit microcontrollers, but who would run for the hills if you asked them to write a program in C and/or create an application to run under an operating system. (Incidentally, the term 'bare metal' refers to a computer system without a base operating system or any installed applications.)

Reports of analogue's death

I can't tell you how many times I've heard the old chestnut that a newspaper prematurely published an obituary for Samuel Clemens, who we know by his pen name of Mark Twain, and that he responded by saying, 'The reports of my death are greatly exaggerated.' It's unfortunate that this story is itself something of an exaggeration, but – as I learned at my mother's knee – one should never let facts get in the way of a good story.

I think it was around the 1980s when I first started to notice industry pundits proclaiming the demise of analogue electronics. 'Digital is destined to rule the world,' they cried. Unfortunately, a lot of young people believed them, leading to a lack of students wishing to learn the analogue arts.

Paradoxically, the resulting dearth of analogue engineers in the 1990s made these people valuable commodities, capable of demanding high wages. Even more paradoxically, engineers skilled in analogue are in ever-increasing demand today. Part of this is because – as analogue buffs delight in telling anyone who will listen – everything is analogue, including digital, which they regard as being a sub-set of analogue (the cheeky scamps).

Much as it pains me to admit it, this is true as far as it goes. Although digital designers like to think of their signals as instantaneously transitioning between 0 and 1 values with razor-sharp edges, these signals take time to transition (think 'slopes') in the real world. Also, the faster we try to convey data through the copper wires on our circuit boards, the more their signals succumb to analogue effects, with their envelopes degrading before our very eyes. The bottom line is that, without the help of analogue engineers, we digital designers would be unable to perform our own magic.

Analogue AI

At the time of this writing, most of the artificial neural networks (ANNs) used to implement artificial intelligence (AI)

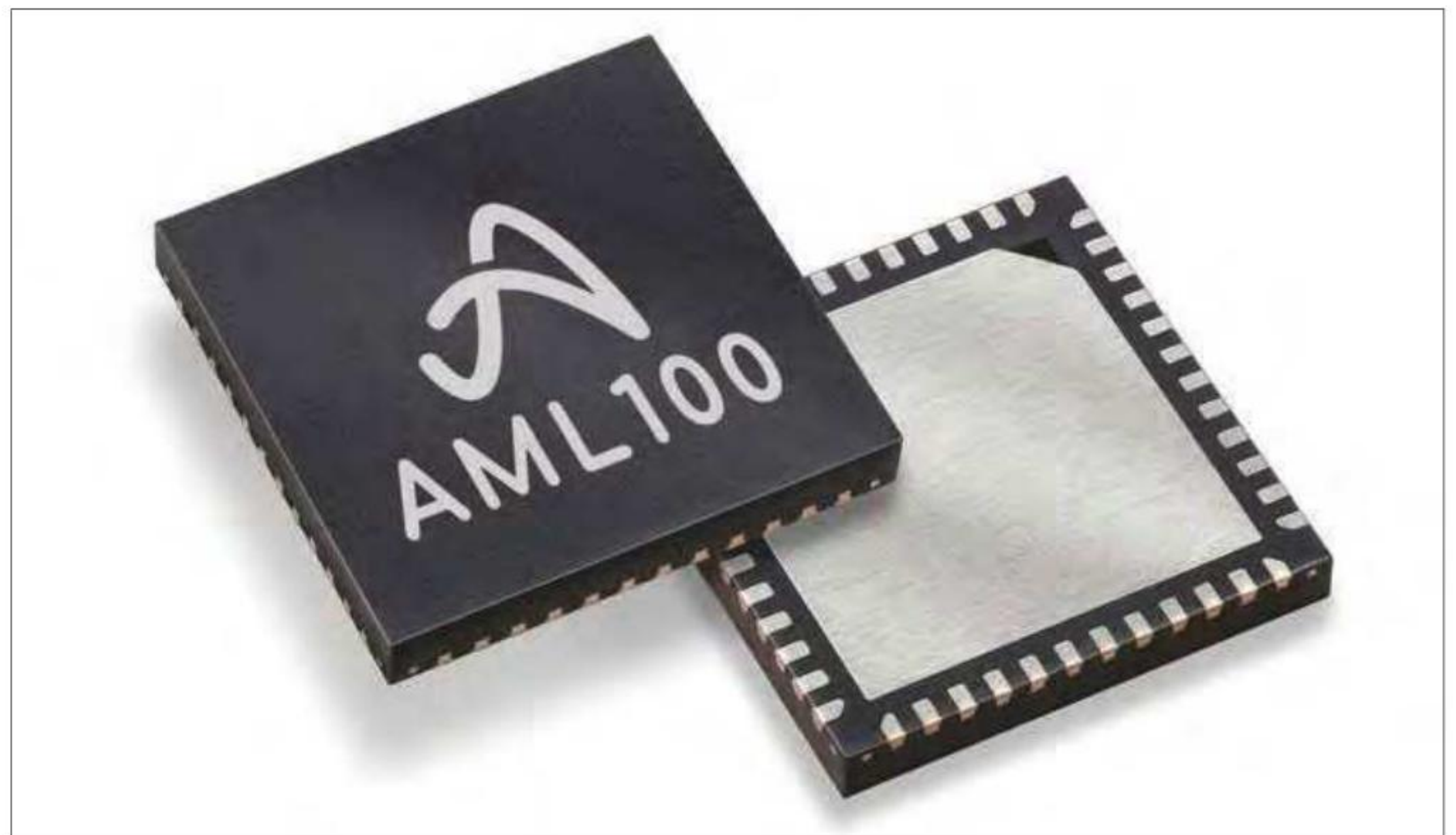


Fig.1. The purely analogue artificial neural network AML100 uses near-zero power to detect events and make inferences and conclusions (Image source: Aspinity).

and machine learning (ML) tasks are realised using digital techniques. By some strange quirk of fate, however, I've recently been seeing an increasing number of analogue implementations. For example, the guys and gals at **Aspinity.com** recently launched the first member of their AnalogML family, the AML100, which they describe as: 'The industry's first and only tiny machine learning solution operating completely within the analog domain' (Fig.1).

The AML100, which is presented in a small 7 x 7 mm 48-pin QFN package, uses near-zero power to detect events and make inferences and conclusions (it actually consumes <20µA while always-sensing). With up to three inputs from sensors like MEMS microphones or accelerometers, the ANN in the AML100 can be trained to recognise things like the sound of glass breaking or a human speaking (it doesn't understand the words, to be clear, but it can tell the difference between a person talking and a cat meowing or a dog barking, for example).

Consider a smart speaker like an Amazon Echo, Apple HomePod, or Google Home. Such a device typically boasts a hierarchy of processors. Since it isn't doing anything for most of the time, the main application processor (AP) spends much of its time asleep, leaving a smaller, lower-power processor to keep a watchful eye (well, ear) open in the hope of hearing the system's wake-word spoken. This wake-word is 'Alexa' in the case of the Echo, and I know two people called Alexa who, much like Queen Victoria, are not amused. Although the wake-word processor consumes less power than the AP, it's still digital in nature, which means it's probably consuming more power than we would like it to, if we were given a choice.

There's also the fact that, out of all the sounds going on in my office (air conditioner blowing, keyboard clicking, Geiger counter beeping, my head banging on the wall, the sound of a man sobbing...), a human speaking occurs only a small portion of the time because I'm alone in the



Fig.2. Mantis AIS SoC next to a 19mm-diameter US one-cent 'penny' piece. (Image source, AIStorm).

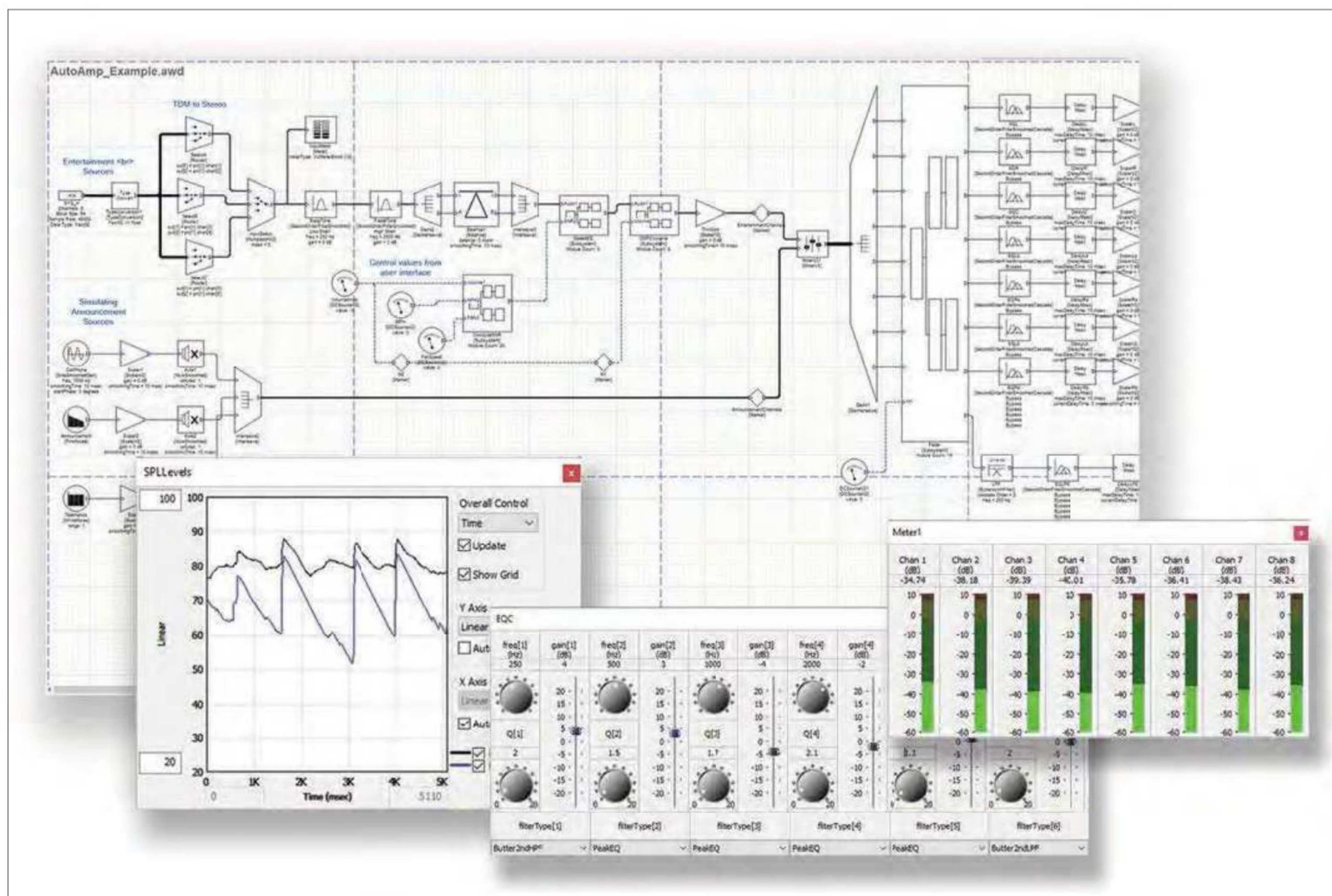


Fig.3. Audio Weaver's intuitive interface (Image source: DSP Concepts).

office and I don't talk to myself (or, if I do, I don't listen to myself). In fact, any human speech is pretty much confined to me warbling on a video conference call or saying, 'Alexa, set a reminder.'

Now, suppose we were to add an AML100 into the hierarchy. In this case, the wake-word processor can itself take a well-deserved snooze. The analogue AI in the always-on AML100 listens to everything that's going on around it, only rousing the wake-word processor when it detects someone speaking. Pretty clever, huh?

Another example of analogue AI is presented by the chaps and chapesses at **AIS Storm.ai**. These are jolly nice people, but it has to be admitted that they are overly fond of saying 'An AI storm is coming.' Consider a traditional CMOS imaging sensor setup in which the output from the sensor is passed through an analogue-to-digital converter (ADC), which feeds an image signal processor (ISP), which passes the data to a digital AI running in a digital signal processor (DSP), microcontroller unit (MCU), graphics processing unit (GPU) or field-programmable gate array (FPGA), none of which are lightweights on the power-guzzling front.

By comparison, AIS Storm's Mantis AI-in-Sensor (AIS) System-on-Chip (SoC) transforms the sensor into the input layer of an analogue AI. Discarding the

digitisation stage, the Mantis (Fig.2) uses the sensor charge to directly couple to the first of multiple layers of analogue neurons. The bottom line is that, using a miniscule amount of energy, the Mantis can evaluate the current situation and make an appropriate determination ('A human just entered the room') before a digital AI would have even laid its metaphorical eyes on the first byte of data from the sensor.

Weaving audio designs

What? You want more? Well, I'm just the man for the task. Let's turn from analogue to digital. I recently spent a happy afternoon chatting with the folks at **DSP Concepts.com**. Not being an audio buff myself, I hadn't really thought about this prior to our conversation, but they pointed out that there are frameworks and design environments to help us work efficiently and productively in almost every engineering discipline other than audio. It's true! If you wish to create a website, you take advantage of a modern web development platform; if you desire to construct a touch panel, you reach for an existing graphics library and widget toolkit; if you ache to implement an AI system, you leverage an appropriate framework; and on it goes.

And then there's audio. I don't know if you've noticed, but compared to the way things were just a few short years

ago, awesome audio experiences and sumptuous soundscapes now feature prominently in our daily lives. The problem is that developers of audio systems have been largely obliged to design everything from the ground up, which is a painstaking and time-consuming way of going about things to say the least. To address this problem, the folks at DSP Concepts have created an awesome product called Audio Weaver (Fig.3).

All I can say is that the things I heard about Audio Weaver and its intuitive, drag-and-drop graphical user interface (GUI) were music to my ears (I'm sorry, I couldn't help myself). Suppose you wish to create something like a smart speaker that involves an array of microphones and one or more loudspeakers. This is where Audio Weaver leaps to the fore with a shemuzzle of Zeusa-phones. You can drag-and-drop functional blocks like noise reduction, echo cancellation, equalisation, compression, beamforming... (there are 500+ modules created by leading audio designers) and connect them together as you wish. Audio Weaver also boasts a runtime core equipped with highly optimised target-specific libraries for use on a wide range of processors from ARM, Cadence, CEVA, TI, Qualcomm... (once again, the list goes on and on).

If you are interested in learning more, you might start with the Audio

Weaver video from CES 2022 (<https://bit.ly/3JOEcRI>). After this, if you wish to explore further, the folks at DSP Concepts say that Audio Weaver is for everyone, from hobbyists to seasoned audio professionals. They currently offer a 30-day free trial for anyone interested in getting started (<https://bit.ly/3M7V5Zf>). Furthermore, with every download of Audio Weaver, they include example audio signal flows and algorithms (loudspeaker processing, SPL meters, reverb...) so that new users don't have to build their audio processing signal chains from scratch.

Are you taking notes?

For more years than I care to remember, I've been using the Notepad editor that comes with Windows for a variety of different tasks, such as taking the contents of a Word document and stripping out all of the hidden control codes, for example.

As useful as Notepad is, however, there are a lot of things it could do better. To be honest, I hadn't really given much thought to this until a few days ago when my eyes were opened to a world of possibilities. In an earlier column (*PE*, December 2021), I introduced my chum Guido Bonelli (aka Dr Duino). If you visit Guido's website (DrDuino.com) you'll see his Dr.Duino Pioneer and Explorer kits, which are awesome when it comes to developing and debugging Arduino Uno and/or Nano-based projects.

Guido has started hosting a monthly online video get together for his customers, during which he shares tips and tricks and new projects. This is followed by a member of the audience demonstrating one of his or her Arduino-based projects. For the inaugural meeting, Guido asked me if I could present one of my own projects to give them an idea of what he's looking for on the participation front. Just for giggles and grins, I walked them through my *12x12 Ping-pong Array* project, which we first started discussing here in *PE*, March 2020.

The thing is, as part of his portion of the proceedings, Guido mentioned a free editor called Notepad++ (pronounced 'Notepad-Plus-Plus'), which you can download from Notepad-Plus-Plus.org (a word to the wise, make sure you click only the 'Download' button located under the image of the cardboard box with 'Notepad++' written on the side – don't be distracted with any of the other 'Download' or 'Start Now' buttons that are there to tempt the unwary).

All I can say is Notepad++ is the answer to my text editor dreams, not least that you can have multiple files open simultaneously, and you can switch back and forth between them by simply clicking their tabs (Fig.4). Furthermore, Notepad++ is a context-sensitive, color-coded editor that inherently understands

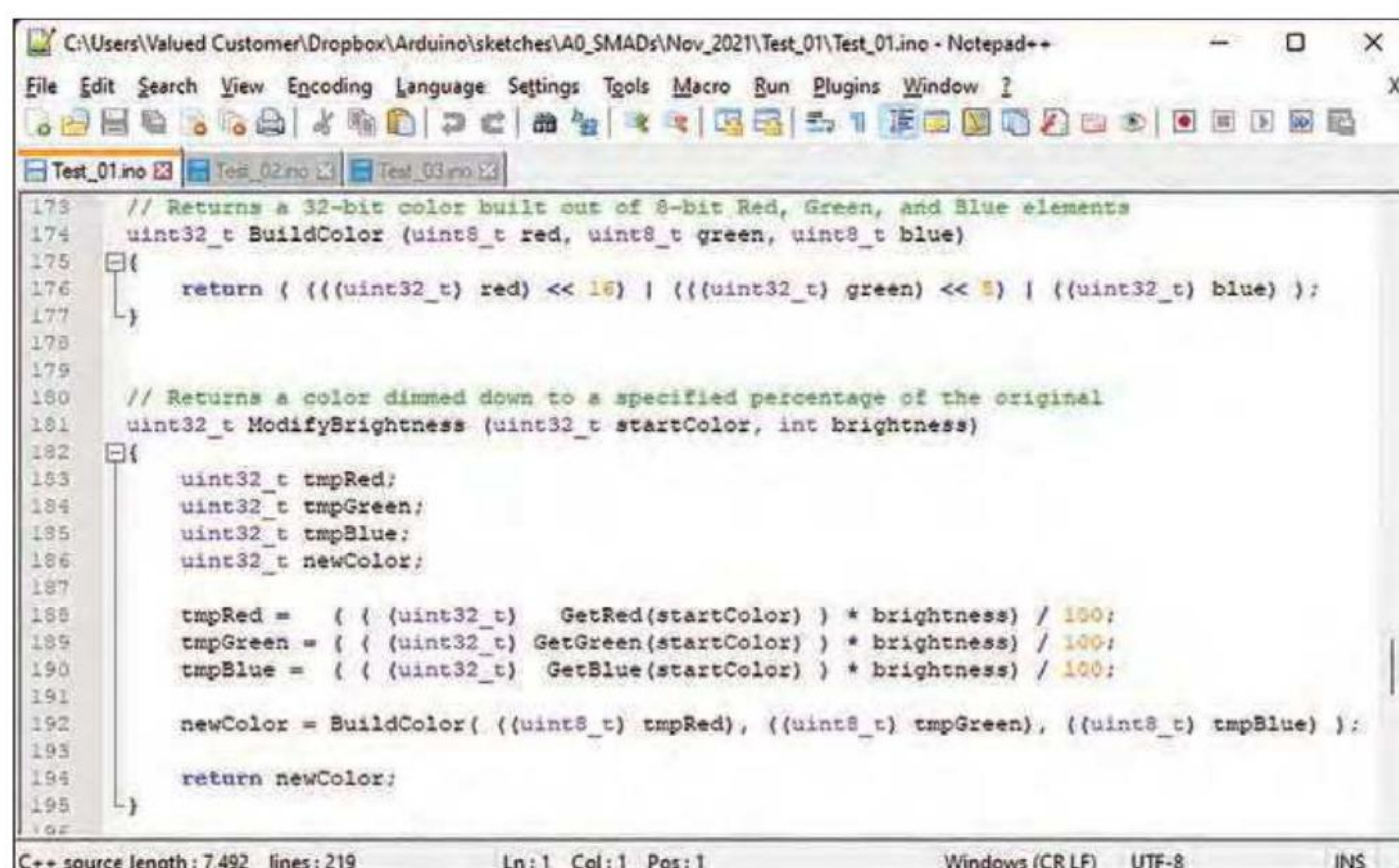


Fig.4. Notepad-Plus-Plus is the answer to my text editor dreams.

languages like BASIC and C/C++. Even better, it allows you to open Arduino sketch (.ino) files and library (.h and .cpp) files.

Although I didn't know it or have use for it at the time (this has changed as we will discuss), Notepad++ also understands things like PIC microcontroller assembly source code (.asm) files and machine code (.hex) files.

Before we proceed, one little trick that can make your life a lot easier is that – assuming you are using Windows (there is no Notepad++ for Macs) – you can simply drag-and-drop a file from a File Explorer window into the Notepad++ working area to open that file (I just ran a quick test to discover that we can do the same thing with the classic Notepad. I tell you; I learn something new every day).

The wonderful world of PICs

Are you familiar with PIC ('pronounced 'pick') microcontrollers from Microchip Technology? These are derived from the 8-bit PIC1650, which was originally developed by General Instruments, who introduced it to the market in 1976. Initially, PIC stood for 'Peripheral Interface Controller,' but it now stands for 'Programmable Intelligent Computer'... probably... possibly... the world hasn't quite agreed on this, so we stick with just 'PIC'.

These days, there is a baffling and bewildering assortment of 8-bit, 16-bit, and 32-bit PICs available, each offering a different collection of features and functions, such as the number of general-purpose input/output (GPIO) pins, the number of analogue-to-digital converters (ADCs), the number of counter/timer/PWM functions, and... the list goes on.

There are many wonderful things about PICs, such as the fact they support a wide range of supply voltages (2.3V to 5.5V in

the case of the 8-bit devices I'm currently working with) and they are available in both surface-mount technology (SMT) packages and lead through-hole (LTH) dual in-line packages (known as DIPs or DILs). There are also some not-no-wonderful facets to these devices, especially the earlier 8-bit ones, whose Byzantine RAM and register banking architecture can bring a strong man to tears (I'm dabbing my eyes as I write these words).

As a result, the last thing you want to do if you are new to PICs is to try to program them in PIC assembly language. All of which brings us to the fact that, for reasons too tortuous to talk about here, I find myself in the position of having to maintain and enhance code whose purpose I may not disclose for a company whose name must remain unspoken ... but I fear I've said too much.

Wouldn't you know it, this code, which dates back to the dawn of time, was captured in PIC assembly language by someone to whom programming did not come naturally. When I originally undertook this task, I was informed that the code was heavily commented. This is certainly true as far as it goes. Unfortunately, the code evolved over time, while the comments... didn't.

'Oh dear,' I said to myself (or words to that effect). I now have code for multiple members of the PIC dynasty to maintain. I've programmed in a variety of assembly languages – I've even designed my own – so I downloaded the 279-page manual for the first device (if there's one thing you can say about Microchip, it's that they have an awesome archive of documentation). Earlier, I used the word 'Byzantine'; I fear this was understating the complexity of the task.

I must admit that I was starting to feel a tad overwhelmed. 'Alas, alack, my end is in sight,' I thought to myself, but then I remembered... Joe.



Fig.5. Hex file size comparison: original (left) vs. new (right).

Are you Positron?

My old friend Joe Farr in the UK has a black belt when it comes to creating PIC-based gadgets and gizmos. He can whip up a printed circuit board (PCB) design for a PIC-controlled thingamajig or thingamabob and have it programmed and ready for action while the rest of us are still rooting through the dictionary to check the spelling of ‘thingamabob.’

So, I set up a Zoom call with Joe, during which I explained my predicament. After looking at the assembly code in question, Joe suggested that we take another tack, which was to rewrite everything in BASIC. I’m sure your eyebrows just started quivering on full alert as did mine. However, Joe went on to explain that – when it comes to programming PICs – he’s a huge fan of the Positron PIC BASIC Compilers created by Les Johnson (<https://bit.ly/3rtDcw8>). A one-time PayPal payment of only £39.99 will gain you access to the latest and greatest compilers, along with any and all future updates and upgrades.

I immediately reached out to Les and placed my order. It really is a small world because Les quickly responded, acknowledging my order and saying that he had read my book, *Bebop to the Boolean Boogie* (<https://amzn.to/3jIt5PU>). It seems that Les also reads my columns here in *PE*, which means he will be reading this one, which means I’d better say only nice things about him.

One point that puzzled me was the use of ‘compilers’ (plural). Les explained that he supplies different compilers for 8-bit and 16-bit PICs, and that both are included. The accompanying integrated development environment (IDE) selects the appropriate compiler based on the device specified in the code, all of which is invisible to the user, which is just the way I like it.

Following an email exchange, Les also told me how his dear old dad started telling him about electronics ‘from when I

was able to walk and talk.’ As a result, Les could name the parts in a television set when he was 3-years old, and he was making radios and amplifiers and such-like by the time he was 7-years old.

The story behind the evolution of the Positron Compilers is captivating. Sadly, we don’t have the time to go into it here. Suffice it to say that these bodacious beauties have been designed from the ground up to produce the most efficient PIC assembly code possible. As an example, I just used my spiffy Notepad++ editor to view and compare the .hex file generated from the original hand-coded assembly with the .hex file resulting from Joe’s BASIC program implementing the same underlying algorithm (I blurred the results to conceal the captivating cunningness of this code). As we see, the new version is around half the size of the original, and fewer instructions generally results in higher performance, all of which leaves my visage adorned with a gleeful grin (Fig.5).

What’s that bit do?

I have so much to talk about regarding my adventures with PICs but – unlike Doctor Who – I’m somewhat limited in terms of time and space. One consideration is that I need some way to program the little ragamuffins. I ended up purchasing a couple of PICkit 3 programmers. I opted for PICkit 3s (<https://amzn.to/3vm0IMR>) rather than PICkit 4s (<https://amzn.to/3jKKwz4>) because (a) they were much cheaper (£18.79 vs. £142.99 in the UK, and a similar difference in the USA where I currently hang my hat), (b) they handle all the devices I currently need to deal with, and (c) Joe told me this was a good way to go. The reason I purchased two units is that Joe says it’s easy to brick these little rascals, in which case you can use one to flash (re-program) the other (the term ‘brick’ or ‘bricking’ refers to rendering an electronic device unusable, often as the result of a failed software or firmware update).

Something else I need is a development board to program and test my PICs. This board has to be tailored to verify the cunning algorithms we’ve loaded into the devices. This includes the board having its own integrated test pattern generator, which we can implement in the form of another PIC (I tell you; my eyes have been opened wide to the wonderful world of PICs).

Joe and I bounced a few ideas back and forth, then we called it a day. You can only imagine my surprise and delight when we Zoomed again the following morning to discover that Joe had gone ahead and designed the board. I will tell you more about this little beauty (the board, not Joe) in a future column. The

reason I mention it here is that, as Joe was walking me through his design, I asked, ‘what’s that bit do?’ To which Joe responded, ‘I included my usual power supply circuit.’

When I enquired further, Joe explained that he rarely powers his creations using a USB interface because you can’t count on it providing you with a solid, spot-on 5V supply. Instead, he implements his own little circuit that can accept a 7 to 25V input, AC or DC (the DC can be either polarity), and it will generate rock-solid 5V and 3.3V DC values to power his electronics.

The fact that the DC can be any polarity struck a chord with me. Most of the little power jacks with which I come into contact have a +ve inner and 0V outer. Having said this, I once picked up a secondhand pair of tasty computer speakers, which I connected to one of my old power blocks. Unfortunately, they expected a 0V inner and a +ve outer, which I realised around the same time the smoke started to appear.

While we were chatting about this, it struck me that this could be a useful circuit for a lot of people, so I asked Joe if he could whip up a standalone version for me to share here, and he promptly did so.

Feel the power!

The circuit diagram for Joe’s handy-dandy power supply unit (PSU) is shown in Fig.6, while the PCB layout is presented in Fig.7. Although your knee-jerk reaction may be that there’s nothing revolutionary here, experienced hands will recognise that the design and physical realisation reflect years of experience.

We start with a bridge rectifier (BR1), which provides full-wave rectification from a two-wire AC input. If the input is DC, this also allows the power to be connected with the +ve on the inner or the outer of the jack. The bridge rectifier is followed by a smoothing capacitor (C1).

The smoothed output from the bridge rectifier is fed to the input of the first regulator (IC1), and also as a raw value to the output connector (SK2). The output from the first regulator is fed as input to the second regulator (IC2), and also to the output connector (SK2).

In my case, I need 5V and 3.3V outputs, so that’s what’s reflected in the schematic. However, by swapping out the regulators, you can generate a variety of voltage combinations, such as 12V and 5V, for example.

Parts list – Joe Farr PSU

SK1 This can be any PCB barrel-type connector with the correct footprint. Alternatively, you can skip the connector and just connect directly to pads ‘a’ and ‘b’ on the PCB.

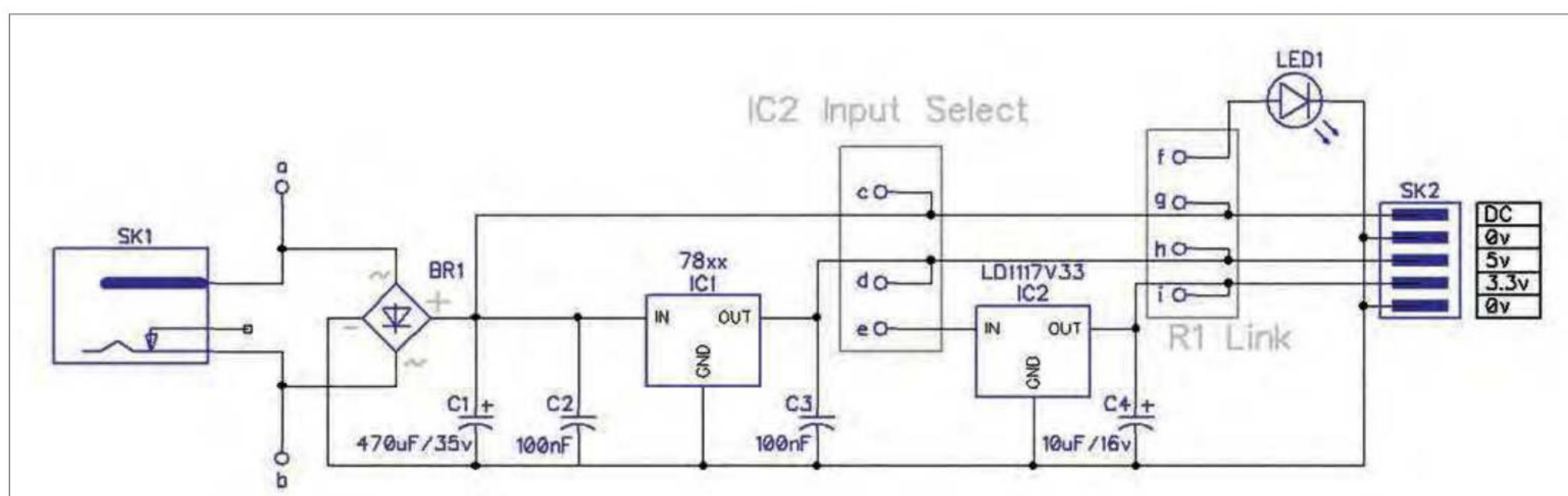


Fig.6. Schematic diagram for Joe Farr's handy-dandy PSU.

SK2 A 5-pin Molex-type connector is ideal as it allows for the board to be easily disconnected from the rest of the project. However, you could use any 5-pin connector with a standard 0.1-inch / 2.54mm pitch, or you could solder header pins, or even solder wires directly to the PCB.

BR1 Any bridge rectifier with a working voltage of at least 50V and rated for a minimum of 1A (always slightly more than the combined maximum load of the board) can be used.

C1 This capacitor must have a voltage rating higher than the maximum expected board input voltage (see Note 1 below).

C2,3 Pretty much any 100nF capacitors with a working voltage greater than 35V can be used.

C4 If IC2 is an LD1117V33 regulator, a 10uF/16V capacitor is ideal here. However, if a 78xx regulator is used for IC2, then this capacitor should be changed for another 100nF capacitor, identical to C2 and C3.

R1 The resistor value used depends on what output voltage will be used to drive LED1 (see Note 2 below). This resistor should be ¼-watt rated.

LED1 Any 5mm or 3mm LED with a forward voltage of around 2V can be used here.

IC1 Any 78xx regulator can be used (see Note 1).

IC2 The original design is specified as using an LD1117V33 LDO (Low Dropout) regulator. Make sure that the input voltage to the regulator (coming direct from the bridge rectifier or from IC1), is within an acceptable range for this regulator (see Note 1).

To capture this design, Joe used the DipTrace schematic and PCB design software package (diptrace.com). Joe has kindly made all of his design files available. You can download a compressed ZIP (file **CB-June22-01.zip**) containing the schematic and foil files from the June

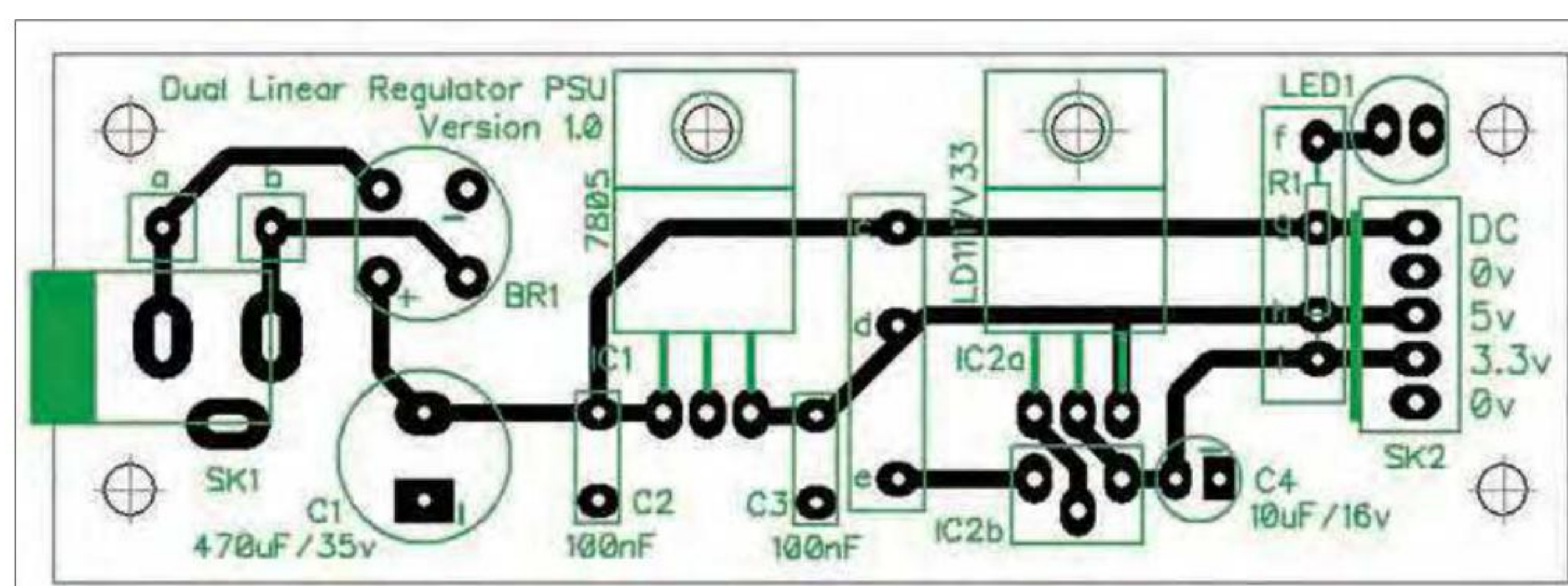


Fig.7. PCB layout for Joe Farr's handy-dandy PSU.

2022 page of the *PE* website (<https://bit.ly/3oouhbl>). Also, file **CB-June22-02.zip** contains all the Gerber and other files required to fabricate the board. If you wish, you can download a free version of DipTrace that will allow you to open, modify, and print the schematic and layout files and also generate updated Gerber files (<https://bit.ly/3uQfZ9B>).

Joe has designed this board to be single-sided, so those with their own facilities can make the PCB. Alternatively, you can ask a PCB house to take the Gerber files and do all the hard work for you.

The voltage regulators don't really need to be bolted to the PCB unless you are attaching heatsinks, which can be homemade if required. On the other hand, bolting the regulators to the PCB does add to the mechanical stability, so it's usually a good idea. However, be very careful to not allow the mounting bolts or heatsinks to come in contact with anything electrically connected to the circuit.

Note that some regulators – the LD1117V33 being a prime example – have the metal mounting tab connected to the device's output pin. By comparison, 78xx regulators have the mounting tab connected to the center (ground) pin.

PSU design notes

Joe provided the following design notes to help you get the most out of his PSU: **Note 1:** The regulator used for IC1 can be any 78xx-style regulator. Do *not* attempt to use a 79xx series regulator anywhere on this board as the pin-out is different.

The regulator works by taking the input voltage and lowering it to match its specified output voltage. The difference between the input and output voltage is dissipated as heat and the regulator can get extremely ('burn the skin off your finger') hot. To minimise the heat being dissipated, try to match the input voltage so that it's around 3V higher than the output of the regulator. When running the board from DC, allow for the bridge rectifier to drop your input voltage by around 1V. You should make sure that the new voltage is sufficient for the input of the regulator you have chosen. When running the board from AC, you need to be careful since the rectified and smoothed DC produced by the bridge rectifier in combination with the capacitor C1 can exceed the maximum voltage rating of the capacitor, especially when there is little or no loading on the PSU output. Always check the datasheet for the specific voltage regulator(s) you are using to make sure you comply with recommended voltage input ranges. If the input voltage to either regulator is too high, that regulator may run hot, with the temperature increasing as you increase the current draw. If the input voltage is too low, the regulator will be unstable and not supply a regulated voltage correctly.

Note 2: Depending on the input voltage applied to the LED, the R1 resistor value needs to be adjusted to give a reasonable brightness. Aiming for around 10mA, which gives a nice brightness without stressing the LED, some suggested



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resistor values for different voltages are: 3.3V = 150Ω, 5V = 330Ω, 12V = 1kΩ, 15V = 1.2kΩ. There are two options for IC2. The original design uses an LD1117V33 3.3V regulator. These regulators should use the IC2a pads as they have a different pin-out compared with the more common 78xx series devices. If you wish to use a 78xx for the second regulator, then the pads labelled IC2b should be used.

Voltage options: Regulator IC1 is always fed directly from the output of the bridge rectifier and capacitor C1. However, depending on requirements, there are two possibilities for driving regulator IC2. If you wish, it can be fed directly from the bridge rectifier (fit jumper C to E). Alternatively, it can be fed from the output of IC1 (fit jumper D to E). This latter option is useful if the voltage output of IC1 is higher than the minimum input voltage required for IC2. This will reduce heat, but it assumes that regulator IC1 has sufficient capacity to provide power to your circuit as well as power to regulator IC2.

Problems with pushbuttons

We didn't have remote control for our television when I was a young whippersnapper growing up in England. In addition to the fact that there were only two TV channels, called BBC1 and ITV (at least, this was the case until 1964 when BBC2 arrived on the scene), people would have considered it to be the height of laziness to control things from the comfort of the sofa rather than getting up and ambling across the room. Similarly, we didn't have things like a dishwasher (unless you were to count my dad) or a garage door opener (unless you were to count me), because these were tasks the fates had ordained we undertake by the sweat of our brows. I don't know what my grandparents would have thought to see me today, ensconced in my command

chair in the family room using spoken commands (thank you, Alexa) to control the lights, turn on the television, and search for programs of interest. I think they would have seen this as a sign that people were turning into 'weeds and wets' as the celebrated English philosopher Nigel Molesworth (<https://bit.ly/3hEJnIj>) might have said regarding his fellow pupils at the legendary English prep school, named 'St Custard's'.

The reason I mention this here is the sentiment, 'What has been will be again, what has been done will be done again; there is nothing new under the sun,' as the Preacher writes in *Ecclesiastes 1:9*. In my previous column (*PE*, April 2022), for example, I noted that the pushbutton and toggle switches of the type with which we are familiar originally appeared on the scene circa 1880 and 1916, respectively. Well, I recently ran across an interesting article – *At the Interface: The Case of the Electric Push Button, 1880-1923* – by media studies scholar Rachel Plotnick (<https://bit.ly/3I3Nc4y>). In Rachel's article we discover that, in 1916, the educational reformer, social activist, and best-selling American author Dorothy Canfield Fisher warned that 'There is a great danger of coming to rely so entirely on the electric button and its slaves that the wheels of initiative will be broken, or at least become rusty from long disuse.' All I know is this tidbit of trivia is going to stick in my mind for years to come because I now think of it whenever I make use of a pushbutton (goodness only knows what Dorothy would have thought about Alexa).

Don't lose your head

I know, I know... I haven't even mentioned the animatronic robot head created by my friend Steve Manley with some (hopefully) helpful suggestions from yours truly.

I also remember that I promised to talk about stepper and servo motors and topics of that ilk, and I shall, but not today because I am being buffeted by a maelstrom of happenings and it's all I can do you keep my nose above the metaphorical waterline.

What? 1000001? Me?

'Eek Alors,' as my dear friend Shears used to say, because this is the month – May 2022 – that I reach the ripe old age of 65 (or 1000001 in binary). Shears was my best friend at high school, and we shared many life experiences, like seeing Pink Floyd play *Dark Side of the Moon* at the Knebworth open air concert in 1975. When I went to university, Shears set off on an extended tour around Europe, largely living off his wits. Sometime after I completed my degree and commenced my first job in Manchester, he came to visit for a weekend and stayed for two years. Oh, the times we had.

Why 'Shears'? Well, his real name was Mark Burkinshaw, so his friends alliteratively renamed him 'Billy Burkinshaw', which (following the release of the *Sgt. Pepper's Lonely Hearts Club Band* album by the Beatles in 1967) led to 'Billy Shears', which was subsequently truncated to 'Shears' (my dad used to call him 'Scissors').

Shears and I would both have reached 65 within a few weeks of each other. Unfortunately, the silly sausage found himself in close vicinity to the Chernobyl nuclear power station in Ukraine when it melted down in 1986 (what are the odds?). Happily, he was able to dance at my wedding when I married my wife (Gina the Gorgeous). Sadly, he passed away a couple of years later from an unusual type of aggressive brain tumor. I miss him a lot. I will raise a glass or three to both of us on my birthday.



Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: max@CliveMaxfield.com

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Circuit Surgery

Regular clinic by Ian Bell

Distortion and distortion circuits – Part 1

Distortion is a key concept in audio and many other areas of electronics. As its name implies, Distortion changes the shape of a waveform. This broad definition would include the effects of ideal filter circuits – for example a low-pass filter ‘round offs’ the sharp-edged changes of a square wave. However, the term is most often used to refer to the effects on signals of non-linearity in circuits, which is what we will explain in detail in this article. Such distortion is usually an unwanted characteristic of signal processing in circuits such as amplifiers and filters, but it also has some positive uses.

Distortion is obviously an imperfection in an amplifier that ought to output an exact copy of the input signal at a higher power level – the output should have the same shape waveform as the input. For audio amplifiers, the amount of distortion produced is often characterised using a measurement called ‘Total Harmonic Distortion’ (THD). The word ‘harmonic’ is used here because distortion due to non-linearity adds frequencies to the output which were not present in the input. In the simplest case, if we input a sinewave (which has a single frequency) distortion will add content to the signal at multiples of the original frequency (its harmonics) – thus, THD is a measure of the amount of harmonic content which the distortion has introduced and serves as a metric of the quality of circuits such as amplifiers.

The ideal (linear) filter mentioned above does not add any frequencies to the output which were not present in the input signal, so there is no harmonic distortion, but it does change the relative amplitude of frequencies present in a complex waveform and hence the shape of the waveform.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*. The examples and files are available for download from the *PE* website.

Musical distortion

Although nonlinear distortion is often unwanted, it does have its uses, with a particularly well-known case being in music effects. Significant amounts of unwanted nonlinear distortion in audio circuits usually sounds harsh and horrible, but applied appropriately it can be a useful creative tool. In musical terms, changing the shape of a waveform alters its timbre. Timbre is the quality of a musical note other than its pitch (fundamental frequency) and loudness – it is the timbre which distinguishes the sound of different instruments playing the same note at the same volume. Therefore, an ability to change the timbre of an instrument adds to the range of possible musical expression. If you start with a ‘pure’ note (something close to a sinewave) a small amount of distortion will add warmth and grain to the sound. Adding more distortion will result in a grittier, fuzzy or rasping sound. Distorting a complex sound will tend to produce a harsher result than produced from a purer input tone. Musical use of distortion is commonly associated with the electric guitar in rock music, where distortion pedals are widely used, but it can be applied to any instrument, even to vocals, and is used in other genres.

FX applications

In the past couple of issues (*PE*, April, May 2022) we published a *Digital FX* project by John Clarke, which provides a variety of sound-processing effects for musicians. This project was mainly aimed at relatively complex effects such as phasing, chorus and pitch-shift, but distortion effects were also included. John also published a distortion pedal project about a year ago (see *PE*, March 2021, *Nutube Guitar Overdrive and Distortion Pedal*). Inspired by these projects we look at the fundamentals of distortion (including the basis of THD), investigate some SPICE simulations related to distortion, and (in *Part 2*) consider some basic circuits used in creating distortion effects.

Linear and non-linear circuits

A linear circuit is one in which the output is related to the input by multiplying it by a simple scaling factor, G_1 . For example, for an input signal (v_{in}) we could write the output signal (v_{out}) as:

$$v_{out} = G_1 v_{in}$$

This is the transfer function of the circuit. If G_1 is equal to or greater than 1 we refer to the circuit as an amplifier with a gain of G_1 , otherwise it is an attenuator. The term ‘linear’ makes sense if we plot a graph of this relationship between v_{in} and v_{out} – it is a perfect straight line going through the origin, as shown in the top trace of Fig.1. The slope of the line is equal to the gain. Any circuit for which the input-output graph is not a straight line is non-linear and will introduce distortion.

For any real circuit the gain (G_1) will vary with frequency. If this variation is specifically designed to pass or reject signals of particular frequency ranges then we have a filter. This can still be linear – the input-output amplitude relationship can still be a straight line at any given frequency, even if the gain (slope of the line) is different at different frequencies. We may find that a real circuit has a very good linear response, but there is a DC offset (or DC error) on the output. We would then write the transfer function as:

$$v_{out} = G_0 + G_1 v_{in}$$

Here, G_0 is the offset. Although it could be said to ‘change the shape of the output waveform’ it is not of primary concern when considering distortion. The graph is still a straight line, although it no longer goes through the origin.

Voltage supply limits

There are a number of reasons why an amplifier might not have a completely linear response, but perhaps the most obvious is that its output signal level is limited. This limit will typically depend on the supply voltage. Examples of input-output relationship for amplifiers with finite maximum output levels are shown in the middle and lower traces in Fig.1. In both cases the output is limited to 1V.

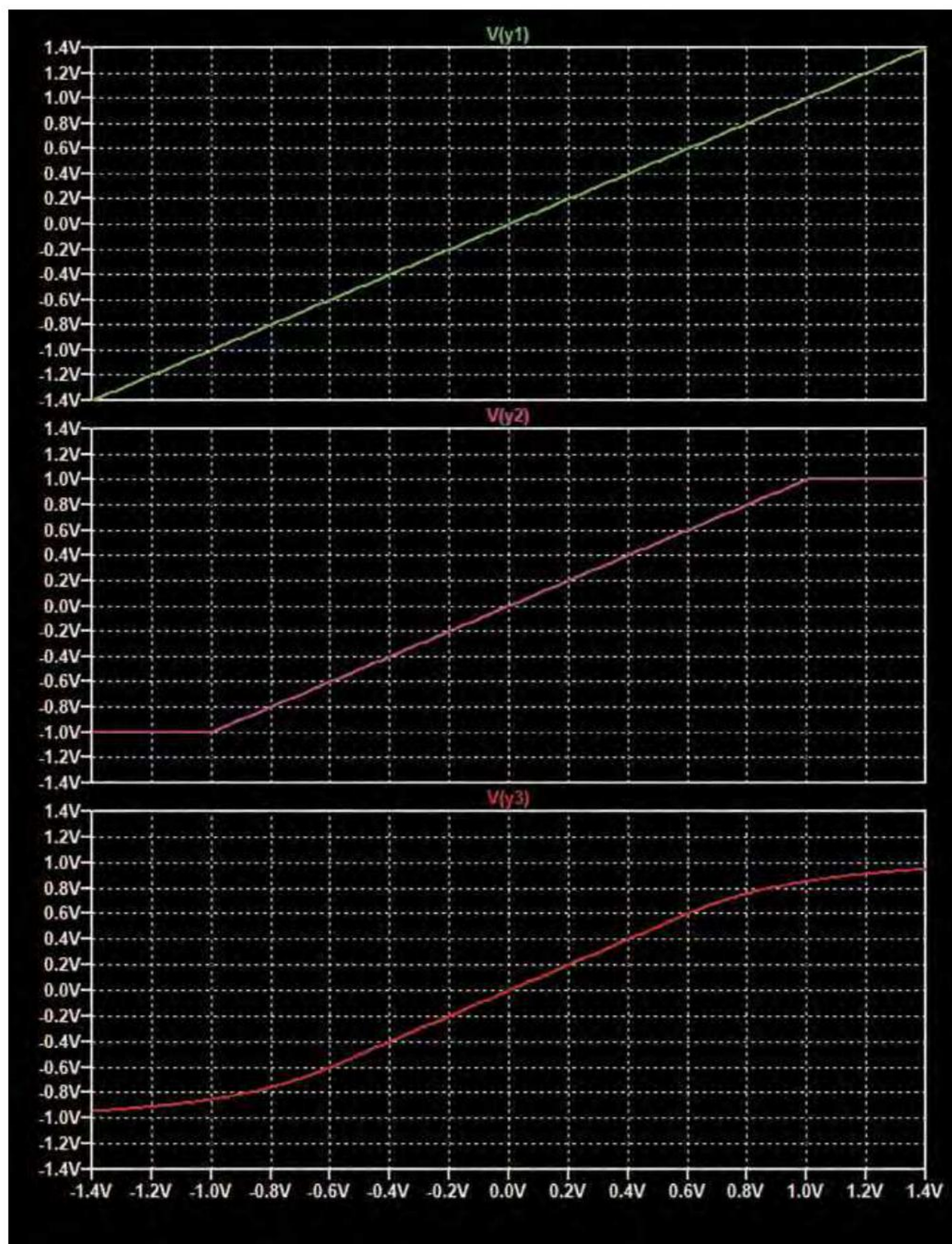


Fig.1. Input-output relationships. Top trace is linear, middle trace has hard limiting (clipping) at $\pm 1\text{V}$ and the bottom trace has softer clipping, also called ‘limiting’ at $\pm 1\text{V}$.

The middle trace has an abrupt transition from the linear response to the limited output and the lower trace shows a more gradual transition from the linear to the limited part of the relationship.

The transfer functions shown in Fig.1 were obtained using behavioural voltage

sources and a DC sweep simulation in LTspice, using the schematic shown in Fig.2. The B1 source simply copies the input (the voltage at node x, from source v1) – this is the linear response (upper trace). The B2 source implements the hard limiting at 1V by outputting the

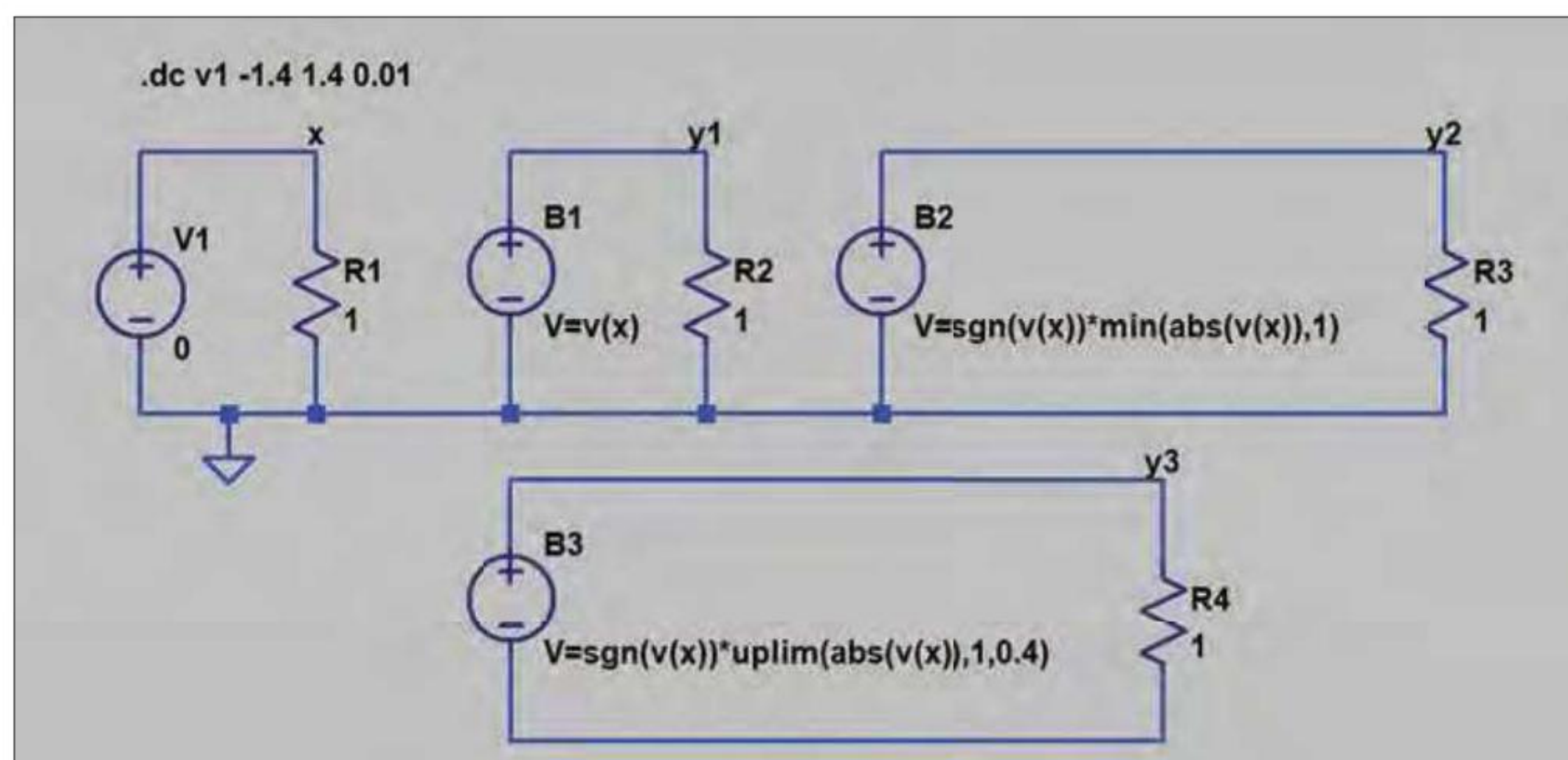


Fig.2. LTspice schematic used to produce Fig.1.

minimum of 1V and the input signal. To get a symmetrical function about 0V, the minimum function is applied to the absolute value of the input voltage ($\text{abs}(x)$ function) and the result is multiplied by the sign function ($\text{sgn}(x)$ returns +1 or -1 based on the sign of the x). The B3 source implements the softer limiting (lower trace) and uses $\text{uplim}(x, y, z)$ instead of $\text{min}(x, y)$. The uplim function is similar to $\text{min}(x, y)$ but with a continuous first derivative and transition width z – this smooths the transition over a range controlled by z . The term, ‘continuous first derivative,’ means there are no abrupt changes in the slope of the graph – no sharp corners like those in the middle trace.

The effect on an input waveform of the three transfer functions in Fig.1 is shown in Fig.3. The top trace is a perfect (undistorted) sine. The middle one shows ‘clipping’ – the highest amplitude parts of the sinewave are flattened. Use of softer transitions produces ‘limiting’ (as in the lower trace), also referred to as ‘compression’. The waveforms were obtained by changing v1 in the schematic in Fig.2 to a 1kHz 1.3V sinewave source and running a transient simulation (.tran 3m).

Describing distortion mathematically

If an amplifier does not have a straight-line input-output relationship, then we are presented with the problem of how we might represent the output mathematically in order to determine how much distortion is present. We could proceed with a very detailed analysis of the circuit, taking into account the characteristics of the all the components, but this may be very difficult, and may produce an equation which is too unwieldy to work with. It would also only be applicable to the one circuit we had analysed, and we would have to start again from scratch for each new circuit.

We need something which is more general and can represent the output of any circuit producing distortion. Our answer is provided by Taylor’s theorem, which was published in 1715 by English mathematician Brook Taylor. Put in simple terms, the theorem states that any a smooth mathematical function can be approximated by a polynomial (known as a Taylor series). A polynomial is an equation formed from a sum of powers of our variable of interest (in this case v_{in}). By ‘powers,’ we mean the original v_{in} (raised to the power 1), v_{in} squared (power 2), v_{in} cubed (power 3), v_{in} to the power 4, and so on. Each power is scaled by a different amount (G_1 , G_2 , G_3 and so on) in which the numerical subscript refers to the relevant power of v_{in} . We

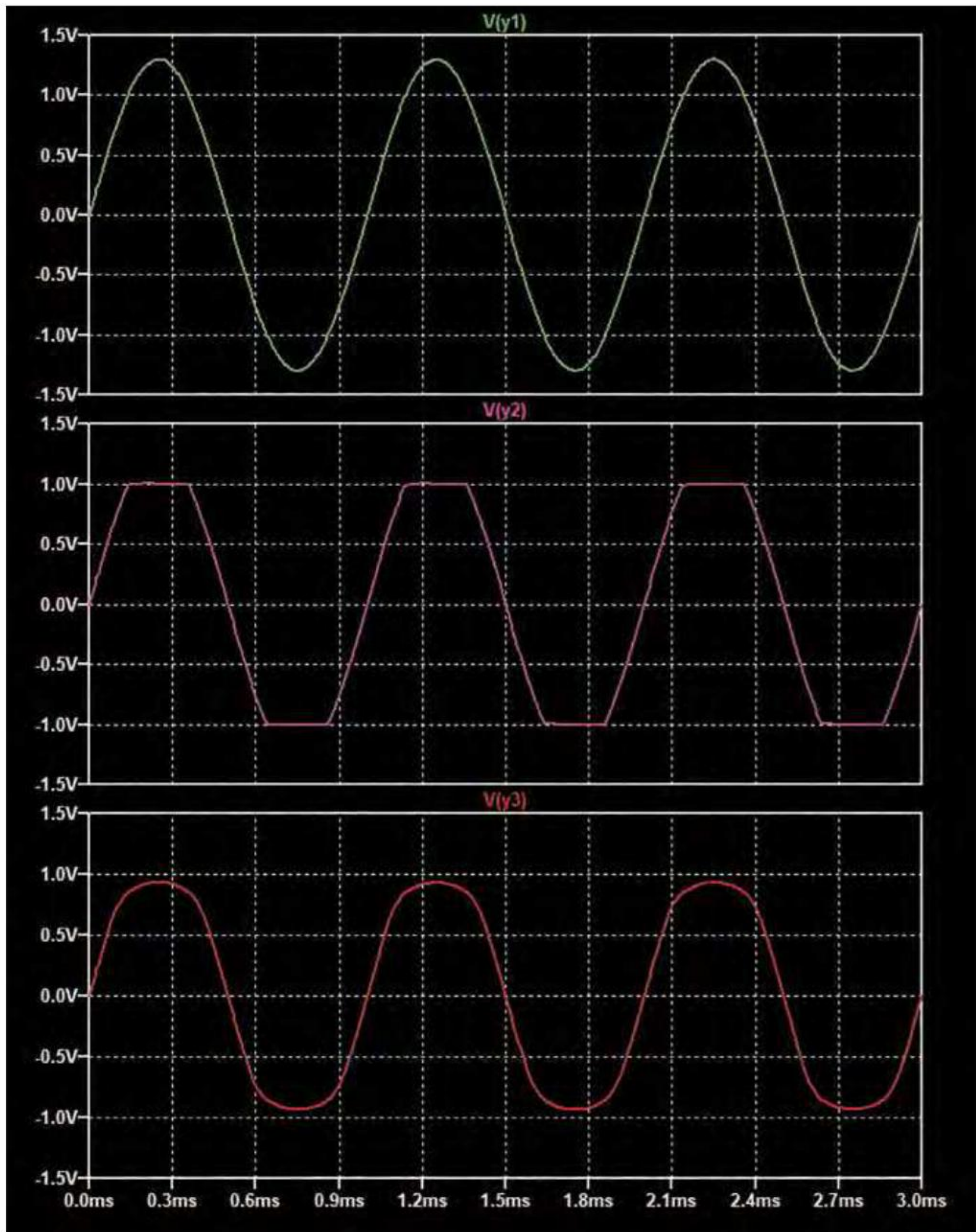


Fig.3. Effect of the transfer functions in Fig.1 on a 1.3V sinewave.

may also include a DC offset G_0 . This leads to a completely general transfer equation for an amplifier with distortion, which is a natural extension of the ideal linear amplifier equation given above:

$$v_{out} = G_0 + G_1 v_{in} + G_2 v_{in}^2 + G_3 v_{in}^3 + G_4 v_{in}^4 + \dots$$

The G values are referred to as ‘coefficients,’ and the items which we are adding up, eg, $G_1 v_{in}$ and $G_1 v_{in}^2$, are referred to as ‘terms’. In principle, there could be a very large number of terms, but in practice the values of the coefficients get very small for higher powers of v_{in} and we are unlikely to need anything beyond a small numbers of terms (less than 10) to calculate THD.

We can separate v_{out} from the above equation into three components: the offset, the ideal output signal and the distortion:

DC offset	G_0
Ideal output	$G_1 v_{in}$
Distortion	$G_2 v_{in}^2 + G_3 v_{in}^3 + G_4 v_{in}^4 + \dots$

If we knew v_{in} and all the coefficients, we could work out the relative levels of the ideal signal and the distortion and so find

the percentage of distortion in the whole output signal. This leads us immediately to a couple of problems: we have not defined v_{in} and we do not know the coefficients.

It would be useful to be able to compare different circuits in terms of the distortion they produce. This is only meaningful if it can be done in a consistent way; it therefore makes sense to use the same type of signal for v_{in} in such a comparison, and indeed for all distortion figures. The special properties of sinewaves make them the perfect choice for the basis of distortion measurement.

Signal spectra

Any periodic waveform can be formed by adding together a set of sinewaves of various frequencies and different amplitudes. This ‘sum of sinewaves’ is known as a Fourier series and was developed by Jean Baptiste Joseph Fourier (1768–1830), a French mathematician and physicist. For example, a square wave may be described as being at 1kHz, but this is just the fundamental frequency; there are other frequencies present too. For a 1kHz, $\pm 1V$ square wave, the sinewaves which can be added together to form it are approximately: (first figure is amplitude) 900mV at 1kHz, 300mV at 3kHz, 180mV at 5kHz, 129mV at 7kHz and so on to infinity. At each odd multiple, n , of the fundamental the amplitude is $1/n$ of the fundamental amplitude.

Looking at this the other way round, we can break any waveform down into its constituent sinewaves, finding the amplitude of each one. If we plot a graph of the amplitude of the constituent sinewaves along a frequency axis, we have the spectrum of the waveform. Part of the spectrum of a square wave is shown in Fig.4. We often plot spectra with log frequency and dB (decibel) amplitude axes, but Fig.4 uses linear axes and this makes it easier to see the $1/n$ odd harmonic amplitude relationship. We will discuss how to plot spectra of waveforms using LTspice next month.

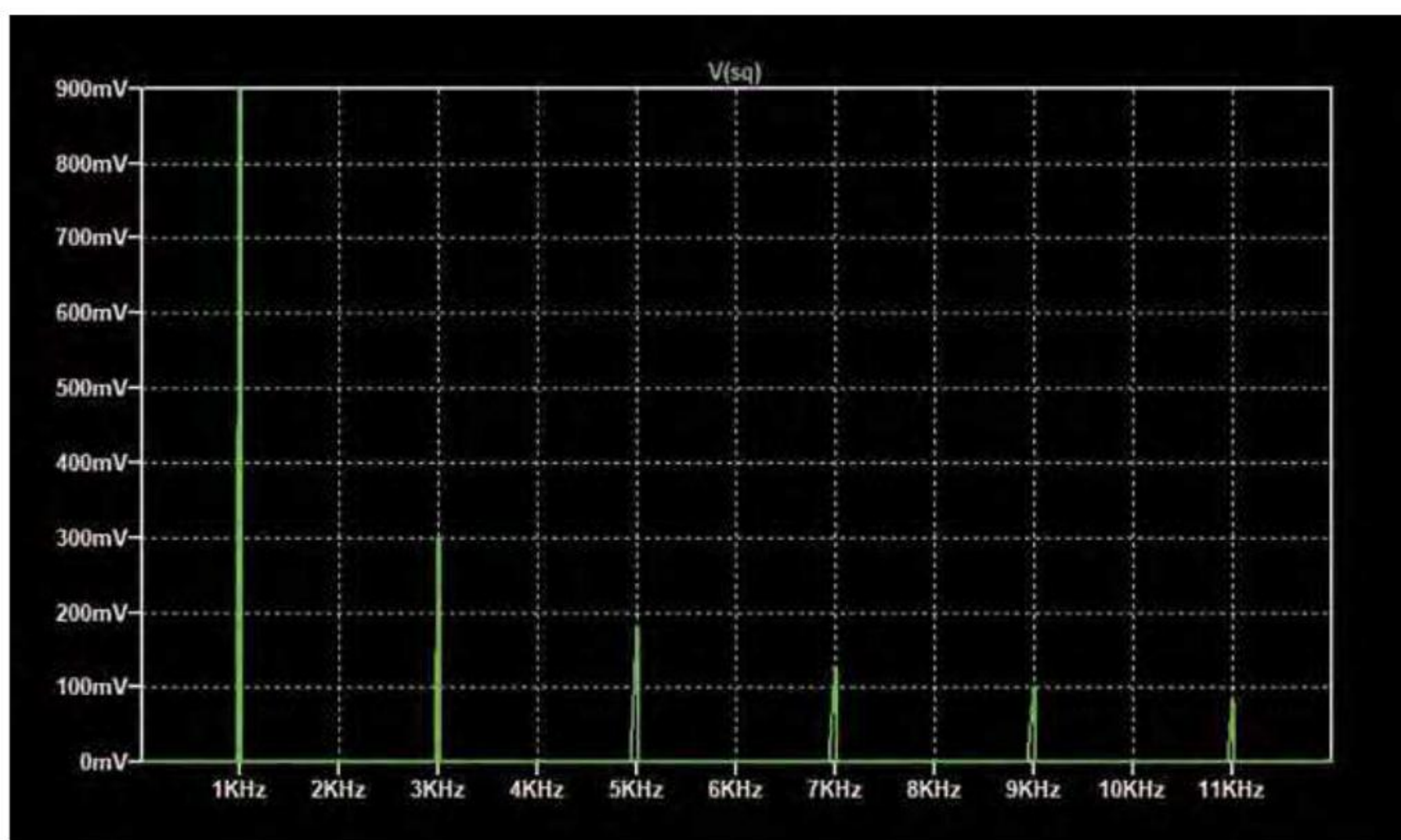


Fig.4. Part of the spectrum of a square wave (linear amplitude and frequency axes).

If we apply a sinewave input to a perfect linear amplifier, we will get a sinewave of the same frequency at the output. The spectrum of both input and output will contain a single frequency component. If the amplifier introduces any distortion, then the output wave shape will no longer be a perfect sinewave (as in Fig.3) and therefore must contain additional constituent sinewaves at frequencies other than the input frequency. Fourier analysis will reveal these frequencies in the output spectrum. Fig.5 shows the spectra of the three waveforms in Fig.3. The top plot – that of the sinewave, shows a single peak at the sinewave frequency – this is the same as the input signal. The other two plots show the additional frequency content produced by distorting the sinewave. Decibel amplitude plots are used here as some of the harmonics are too small to see on a linear scale.

Harmonic distortion

Assuming v_{in} is a sinewave, we can proceed with using our general transfer equation to calculate the distortion. To keep things simple initially we will assume that the only distortion term present in our output is the v_{in} squared term, $G_2 v_{in}^2$. We will also ignore the DC error. We will use a cosine input signal, as this is a bit more convenient in terms of the calculations than a sine, but the basic properties in terms of spectra are the same; so, we have:

$$v_{out} = G_1 v_{in} + G_2 v_{in}^2$$

And

$$v_{in} = V_m \cos(\omega t)$$

Where V_m is the peak amplitude of the cosine input wave, ω is its frequency in radians per second (2π times the frequency in hertz) and t is time. Substituting the v_{in} expression into the v_{out} equation gives:

$$v_{out} = G_1 V_m \cos(\omega t) + G_2 V_m \cos^2(\omega t)$$

To deal with the $\cos^2$ term we use one of the basic trigonometric identities known as the double-angle formulae, which are related to Pythagoras' theorem. Specifically, we need to use:

$$\cos(2X) = 2\cos^2(X) - 1$$

Or

$$\cos^2(X) = \frac{1}{2}(1 + \cos(2X))$$

So the v_{out} equation becomes:

$$v_{out} = G_1 V_m \cos(\omega t) + \frac{1}{2} G_2 V_m + \frac{1}{2} G_2 V_m \cos(2\omega t)$$

Here, $\frac{1}{2} G_2 V_m$ is a DC voltage (there is no cosine or other frequency dependent value in this term). This will add to any existing DC offset (which we ignored earlier). Of more interest is the term $\frac{1}{2} G_2 V_m \cos(2\omega t)$, which represents a signal at *twice* the original frequency (2ω).

Since we are looking for general equations, the details of the coefficients such as $\frac{1}{2} G_2 V_m$ are not of particular interest

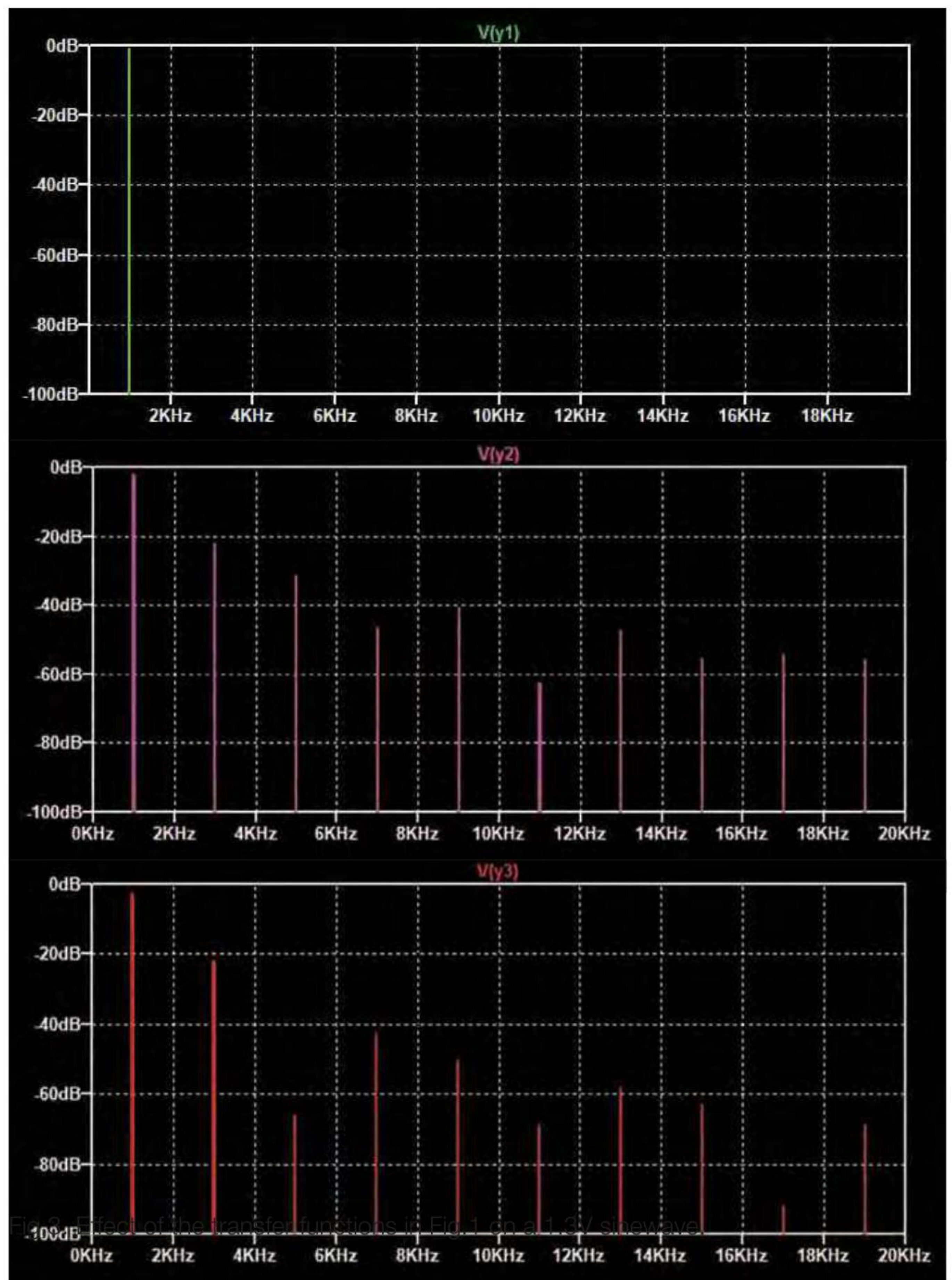


Fig.5. Spectra of the waveforms in Fig.3 (dB amplitude and linear frequency).

at this point, and we can tidy up the equation using $B_2 = \frac{1}{2} G_2 V_m$, and similarly for other terms:

$$v_{out} = B_0 + B_1 \cos(\omega t) + B_2 \cos(2\omega t)$$

To obtain this equation we started with a simplified version of our distorted output signal in which we only included the $G_1 v_{in}^2$ term from the distortion. If we include more distortion terms the calculation proceeds in the same way – we use relevant trigonometric identities to deal with the various powers of cosine. There is a lot more work to do as the equations get bigger, but the result comes out in a well-structured form:

$$v_{out} = B_0 + B_1 \cos(\omega t) + B_2 \cos(2\omega t) + B_3 \cos(3\omega t) + B_4 \cos(4\omega t) + \dots$$

Remember, this is the output from a distorting amplifier with a single sinewave (specifically a cosine in this case) at the input. Just as we did with our general output signal, we can separate v_{out} into three components: the offset, the ideal output signal and the distortion:

DC Offset	B_0
Ideal output	$B_1 \cos(\omega t)$
Distortion	$B_2 \cos(2\omega t) + B_3 \cos(3\omega t) + B_4 \cos(4\omega t) + \dots$

We see that the distortion (of a sinewave input) consists of a set of sinewaves (cosines) at frequencies of twice (2ω), three times

(3ω), four times (4ω), and so on, times the input frequency. Frequencies which are whole-number multiples of a particular frequency are called harmonics of that fundamental frequency. This result shows us that for a sinewave input the distortion is entirely due to harmonics of the input signal, which is why we use the term ‘harmonic distortion’.

If our input signal is more complex than a single sinewave then the distortion will contain frequencies other than the harmonics. For example, if the input signal contains two sinewaves of different frequencies (ω_1 and ω_2) the distortion will include, in addition to the harmonics of both frequencies, the sum ($\omega_1 + \omega_2$) and difference ($\omega_1 - \omega_2$) frequencies, and other combination frequencies. This is known as intermodulation distortion. Intermodulation distortion is of particular importance in radio circuits and has relevance to musical distortion effects.

The term $B_2 \cos(2\omega t)$ in the equation above tell us the signal level of the second harmonic distortion, but on its own it is not very useful because what we really need to know is how large the distortion is in comparison with the ideal output. We therefore define the second harmonic distortion, D_2 , as:

$$D_2 = \frac{|B_2|}{|B_1|}$$

We can also define distortion values for the other harmonics in a similar way. Terms such as $B_2 \cos(2\omega t)$ are time dependent and actually show the level of that distortion component at each instant of time. When comparing circuits, it is more useful to know the average distortion over time. The average voltage of a zero-offset sinewave is zero, so we use root mean square (RMS) values – this is equal to the DC voltage which provides the same power dissipation in a fixed resistor as the AC signal.

For a sinewave with V_m peak amplitude, the RMS value is well known to be $V_{RMS} = V_m / \sqrt{2} = 0.707 V_m$. In our distortion calculation the wanted output signal is $v_1 = B_1 \cos(\omega t)$ so its RMS value is $V_{1,RMS} = B_1 / \sqrt{2}$. From this we can find the power of the ideal output signal (P_1) into an arbitrary load resistor R :

$$P_1 = \frac{v_{1,RMS}^2}{R} = \frac{B_1^2}{2R}$$

Similar we can find the power of the second harmonic output, and then the ratio of the two, and hence the second harmonic distortion, D_2 .

$$P_2 = \frac{B_2^2}{2R}$$

$$\frac{P_2}{P_1} = \frac{B_2^2}{B_1^2} = D_2^2$$

Total harmonic distortion

It would be useful to know the total power of the distortion and compare this with the wanted signal. We might be tempted to simply go ahead and add up $P_2, P_3, P_4 \dots$ to get the total power. A mathematician might object at this point and say that what we can do in terms of finding the power of single signal might not work when we have a whole set of them (the distortion spectrum). Fortunately, it can be shown, using something called Parseval’s Theorem, that we can add up these power values. Parseval’s Theorem shows that we can work out the power or energy of a signal using its spectrum (Fourier series) or the original signal and get the same answer. The total power of the distortion, $P_D = P_2 + P_3 + P_4 + \dots$, is therefore:

$$P_D = \frac{B_2^2}{2R} + \frac{B_3^2}{2R} + \frac{B_4^2}{2R} + \dots$$

Dividing by the power of the wanted signal gives:

$$\frac{P_D}{P_1} = \frac{B_2^2}{B_1^2} + \frac{B_3^2}{B_1^2} + \frac{B_4^2}{B_1^2} + \dots$$

$$\frac{P_D}{P_1} = D_2^2 + D_3^2 + D_4^2 + \dots$$

Representing the overall distortion with single value (D) we can write:

$$D^2 = \frac{P_D}{P_1} = \frac{P_2 + P_3 + P_4 + \dots}{P_1}$$

D is the *Total Harmonic Distortion* and is defined in terms of the individual harmonic distortions by:

$$D = \sqrt{D_2^2 + D_3^2 + D_4^2 + \dots}$$

Power is proportional to the square of the voltages concerned, so we can also write the THD as:

$$D = \frac{\sqrt{P_D}}{\sqrt{P_1}} = \frac{\sqrt{v_2^2 + v_3^2 + v_4^2 + \dots}}{v_1}$$

Here, v_1 is the amplitude (or RMS) value of the fundamental and $v_2, v_3 \dots$ are the amplitudes (or RMS) values of the distortion products. THD can be expressed as a percentage or as a value in decibels $20 \log_{10}(D)$. Unfortunately, this is not the only definition of THD in use. The alternative approach is to define D directly as the power ratio P_D/P_1 . Expressing the power version in decibels (using $10 \log_{10}$) gives the same value as the voltage-based version in decibels, but the percentage figures are different – so take care when looking at THD figures to make sure you know how it is being expressed.

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Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 36: How it works: The Electronic Door Lock software



In the previous **Make it with Micromite** article (PE, April 2022), we discussed the hardware assembly of our current mini-project; the *iButton Electronic Door Lock (iEDL)*. As a brief recap, the *iEDL* hardware comprises a handful of components and modules attached to a Micromite; these are: a touchscreen, an iButton reader (on pin 9), an LED (on pin 10), a relay module (on pin 21), and a piezo sounder (between pins 22 and 26). To bring all these hardware elements alive we will use MMBASIC program code running on the Micromite so that they work together as a system. This month, we will discuss the *iEDL* software, providing a simplified overview, and explaining how it works.

System features

We begin by listing all the features that will be incorporated into the *iEDL* and give a brief explanation of why these features are required. From this features list, we will then map out the required process flows that the *iEDL* needs to follow, which will in turn make the program code much easier to understand. It will also help define all the different screens with which a user will interact.

We will also describe how an *iEDL* reader uses three pieces of configuration data: the *Admin-Key-ID*, a *Description* and the *Access-Group-ID* for the *iEDL*. Turning to the iButton, we will discuss how different configuration data is formatted (and stored) in an EEPROM iButton key (hereafter referred to as an 'iKey'), and how this configuration data is used by the *iEDL*.

One point worth emphasising here is that any code presented in this series is primarily provided for learning purposes. Once you feel that you understand how a topic works, we

strongly encourage you to customise the program code so that it suits your own preferences and

specific requirements. Remember, changing program code really is the best way to learn more about the amazing power of MMBASIC.

System features

The whole system uses the following three elements:

- **User iKey** (one issued to each user). Configuration data is stored in the iKey's EEPROM and comprises: the keyholder's *Name*, permitted *Door-Group-Access-Levels* (a value from 0 to 255), and an *Identifier* (the word 'iKey').
- **iEDL** (one required for each secured door). Configuration data is stored in the *iEDL*'s memory and comprises: a *Description* for the *iEDL* (eg, its location), an *Access-Group-ID* (a number from 1-8), and an *Admin-Key-ID* (a specific iButton's unique 8-byte ID value).
- **Single Admin-Key** to configure the whole system and issue iKeys.

Together, these three elements need to provide the following high-level capability:

- When a person taps their user iKey onto an *iEDL*'s reader, their access level (stored in the iKey's EEPROM) is checked with the *Access-Group-ID* stored in the *iEDL*. The user is then either granted or denied access to the secured door; with a suitable message (containing their *Name*) displayed on the *iEDL*'s touchscreen
- Any iButton without the iKey *Identifier* (read from EEPROM) will not be considered part of the system, and will result in an 'Invalid iKey' message being displayed
- If the *Admin-Key* is detected – the iButton's unique ID matches the *iEDL*'s stored *Admin-Key-ID* – then the *iEDL* switches into 'Admin Mode'. This allows any configuration data to be adjusted either in the *iEDL* itself, or in a user's iKey. For example, in Admin Mode, you can change the *iEDL*'s location *Description*, or you can alter the *Door-Group-Access-Levels* in a user's iKey
- Admin Mode is also used for issuing new iKeys to new users
- When the program code is run for the very first time, the *iEDL* needs to define the single *Admin-Key-ID* by displaying a simple prompt to tap the desired iButton (any type) onto the *iEDL*'s reader. Once confirmed, the *iEDL* will automatically enter Admin Mode so that the default *Description* ('Micromite iEDL'), and default *Access-Group-ID* ('1') can be altered.

Reasons for features

Let's expand on the above points and discuss why some of these features have been implemented. The overriding

Micromite code

The code in this article is available for download from the PE website.

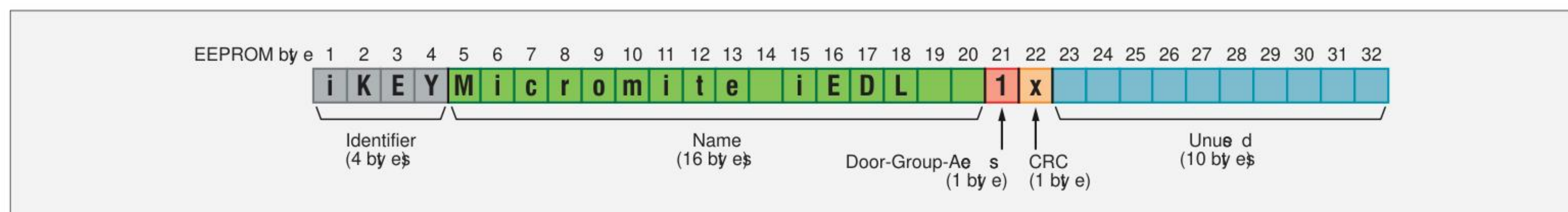


Fig.1. The user iKey stores configuration data in EEPROM – 22-bytes of the available 32-bytes are used.

idea behind the *iEDL* is for it to be a secure alternative to the classic digital combination lock. The big disadvantage with most digital combination locks is that when an authorised user enters the ‘secret’ code on the keypad, any ‘unauthorised’ person nearby may be able to observe the code, re-enter the code and gain access. The *iEDL* eliminates this disadvantage by not requiring a code to be entered; instead, it allows access only with the possession of a valid iKey. All a keyholder needs to do is tap their iKey onto the *iEDL*’s iButton reader.

However, we don’t just want *any* iButton to be able to ‘unlock’ the door, so we’ve added some intelligence to the system with door access permissions. An *iEDL* is configured with an *Access-Group-ID*, which is a single value between 1 and 8. Also, when a user is issued with an iKey, the door group IDs that the keyholder is permitted to access is stored on their iKey (this can be multiple *Access-Group-IDs*). The *iEDL* can then determine whether to grant access to the keyholder. If access is granted, the *iEDL* releases the electronic door locking mechanism.

Where multiple *iEDLs* are implemented (ie, multiple doors are secured), the door access permissions allow us to configure a user to be granted access to some groups of doors but denied access to others.

Another important design requirement (where multiple *iEDLs* are implemented) is to eliminate the need for having to connect the *iEDLs* to each other. By avoiding potentially complex cable runs between doors, it not only makes for an easier install, but also makes the solution very scalable. So, regardless of whether just one *iEDL* is used (for a single door), or multiple *iEDLs* for multiple doors, each *iEDL* can be regarded as a standalone unit which just needs power (and a connection to the door’s electronic locking mechanism).

The *iEDL*’s stand-alone capability (and the ease of scalability) is possible thanks to the smart way in which EEPROM iButtons have been implemented as iKeys. Not only is a keyholder’s *Name* stored on their iKey (allowing their *Name* to be displayed on the *iEDL*’s screen when the user taps their iKey onto the iButton reader), but also the groups of doors that the keyholder can access is stored on the iKey too.

Another design aim for the *iEDL* was for there to be no need to connect it to a computer. This is achieved by including a touchscreen. Being able to put an *iEDL* into Admin Mode means it is possible to configure certain attributes of the system via the touchscreen (instead of via a computer). The touchscreen also enables an *iEDL* to be used to issue iKeys to keyholders (because the keyholder’s *Name* can be entered on a touch-keypad).

To switch an *iEDL* into ‘Admin Mode’, we have created a dedicated Admin iButton. Whenever this Admin iButton is presented to an *iEDL*, it switches the *iEDL* from ‘Normal Mode’ to Admin Mode, thereby giving access to all the configuration functionalities. Note that the Admin iButton is not used to unlock a door.

Summary of features and configuration data

Let’s summarise these main features, along with defining some of the more specific details about the configuration data for the *iEDL* and the iKey. Note that no configuration data is required for the *Admin-Key*.

- An *iEDL* has two modes of operation: Normal and Admin
 - **Normal Mode** is the default mode. In this mode the *iEDL* is simply waiting for any iButton to be tapped onto the iButton reader
 - **Admin Mode** allows the system to be configured with various settings, and to issue (and check) iKeys.
- The *iEDL* configuration data is stored in the Micromite’s Flash memory, and comprises the following:
 - *Admin-Key-ID* – this is the 8-byte ID number of the iButton; ie, the iButton’s Family-Code, its 6-byte ID, and the CRC (8 bytes stored as the string: `AdminKeyID$`)
 - *Description* for the *iEDL* – eg, a location description (16 bytes stored as the string: `Desc$`). This is displayed at the top of the screen when the *iEDL* is in Normal Mode
 - *Access-Group-ID* – a number from 1 to 8 (1 byte stored as the variable: `AccessGrpID`).
- There are two types of iButton recognised by an *iEDL*: User iKey and Admin iKey
 - User iKey is based on a DS1971 iButton (ID + 256-bit EEPROM)
 - Admin Key can be any type of iButton. It is used to switch the *iEDL* from Normal Mode to Admin Mode.
- User iKey configuration data has a capacity of 32-bytes; however, (referring to Fig.1) only 22-bytes are used:
 - *Identifier* containing the ASCII characters ‘iKey’ to signify it is an iKey (4 bytes)
 - Keyholder’s *Name* (16 bytes)
 - Keyholder’s *Door-Group-Access-Levels* (1 byte)
 - Error-checking CRC (1 byte).

The *iEDL* functionality has been broken down into four distinct process flows:

1. Normal Mode
2. Power Up
3. Admin Mode (reader configuration)
4. Admin Mode (iKey configuration).

We will now discuss each one in turn.

Process flow 1: iEDL Normal Mode

In Normal Mode, the *iEDL* will display the *iEDL*’s *Description* on the touchscreen and a flashing message will prompt the user to tap their iKey onto the iButton reader.

From the user’s perspective, all they need to do is tap their iKey onto the *iEDL*’s iButton reader. If they have permission for the door group that the *iEDL* belongs to, then the user will see a confirmation message displayed on the *iEDL*’s touchscreen, and they are granted access. However, if the keyholder doesn’t have permission for the door group then access is denied, and an ‘access denied’ message is displayed.

If the Admin Key is detected by the *iEDL*, then the *iEDL* switches to Admin Mode. Finally, any invalid iKey will result in an ‘Invalid iKey’ message being displayed.

To map out the process flow, the above can be summarised as the following:

- Display the *iEDL Description* and wait for an iButton
 - When an iButton is detected, read the 8-byte ID (and error check with CRC)
- Is it the Admin Key? If yes, then switch the *iEDL* into Admin Mode

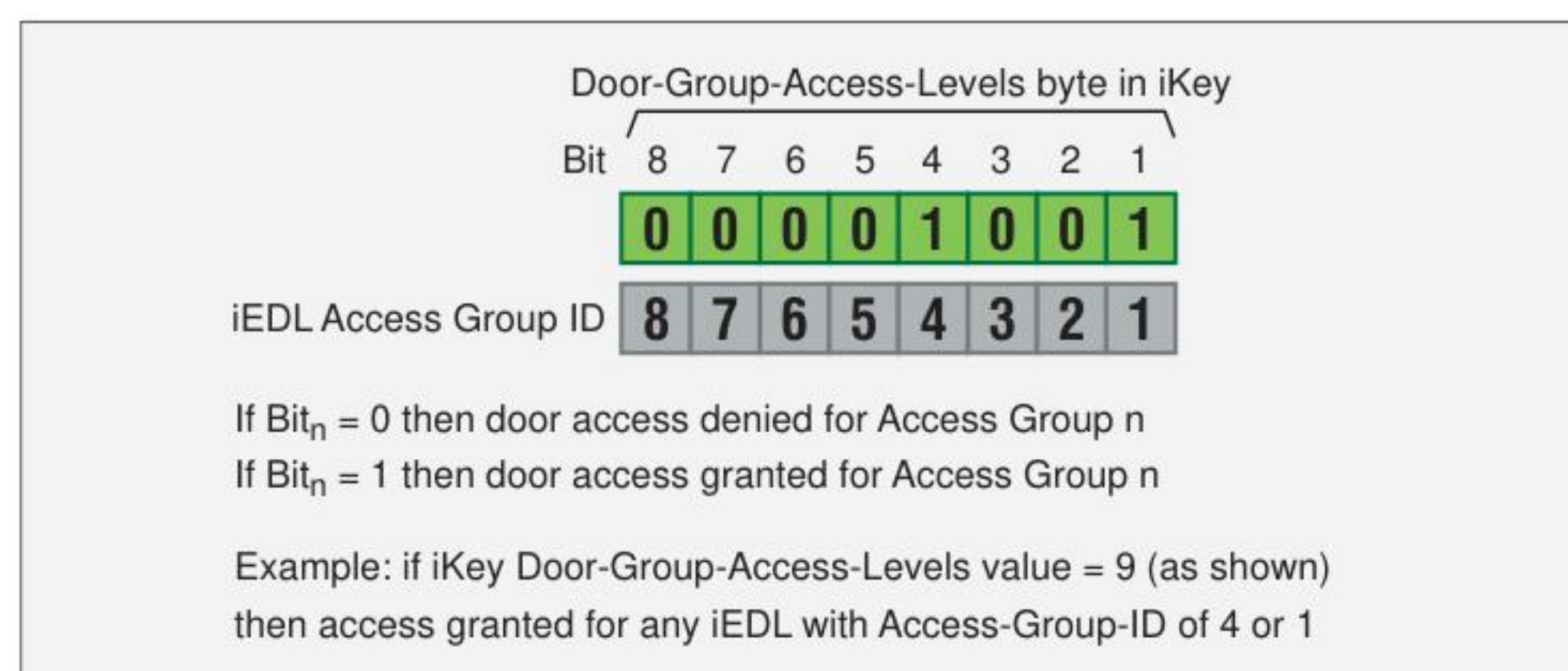


Fig.2. The eight bits in the *Door-Group-Access-Levels* byte (stored in the iKey's EEPROM) determine which of the eight possible *Access-Group-IDs* that the keyholder can access. For example, if the *Door-Group-Access* value is 9 (binary: 00001001), then they keyholder only has access to *iEDLs* that have their *Access-Group-ID* set to either 1 or 4.

- Is it a DS1971? If yes, then read EEPROM to get: the *Identifier*, the keyholder's *Name*, their *Door-Group-Access* permission value and the CRC. If not a DS1971, or the *Identifier* doesn't match 'iKey' then display an 'Invalid iKey' message
- If the *Identifier* and the CRC are both correct, then check door permissions with the *iEDL's Access-Group-ID* to determine if access should be granted or denied (with an appropriate message also displaying the keyholder's *Name*). If access is granted, then momentarily trigger the relay module. (See Fig.2 for more details about how the door permissions work.)

Refer to Fig.3 to see the above list converted into a process flow diagram. This diagram is a useful reference when working through the *iEDL's* program code and makes program comprehension much easier.

Process Flow 2: Power up

On Power up, the *iEDL* must determine if this is the first time that the software has ever run, and if so, it prompts the user to define one iButton for use as the *Admin-Key*; otherwise, it starts the *iEDL* in Normal Mode (discussed above).

To determine if the *iEDL* software has previously been run, the program code must first read the contents of the Micromite's Flash memory by using the MMBASIC command VAR RESTORE. By using this command at the very beginning of the program, two strings (AdminKeyID\$ and Desc\$) and one variable (AccessGrpID) are automatically loaded with whatever is currently stored in Flash memory. So, the very first time the *iEDL* software is run, the two strings will be empty, and the variable will have a value of 0. Hence, by checking if AdminKeyID\$="" (shortly after the VAR RESTORE command) it can be determined if the program code is running for the first time.

If it is running for the first time, then a message prompts for an *Admin-Key* to be defined, and the following points then become relevant:

- The *Admin-Key* can be any type of iButton (ie, the family code is irrelevant; it is just the iButton's unique 8-byte ID number that the *iEDL* will read)
- The user needs to be prompted to tap the desired *Admin-Key* a second time. This guarantees a match so that the user knows which key it actually is (it can become confusing when surrounded by many iButtons!)
- Once the *Admin-Key* has been confirmed, the iButton's unique ID is stored in the *iEDL's* Flash memory by using the command: VAR SAVE AdminKeyID\$)
- If a different iButton is presented on the second occasion, the user is prompted to repeat the process from the start

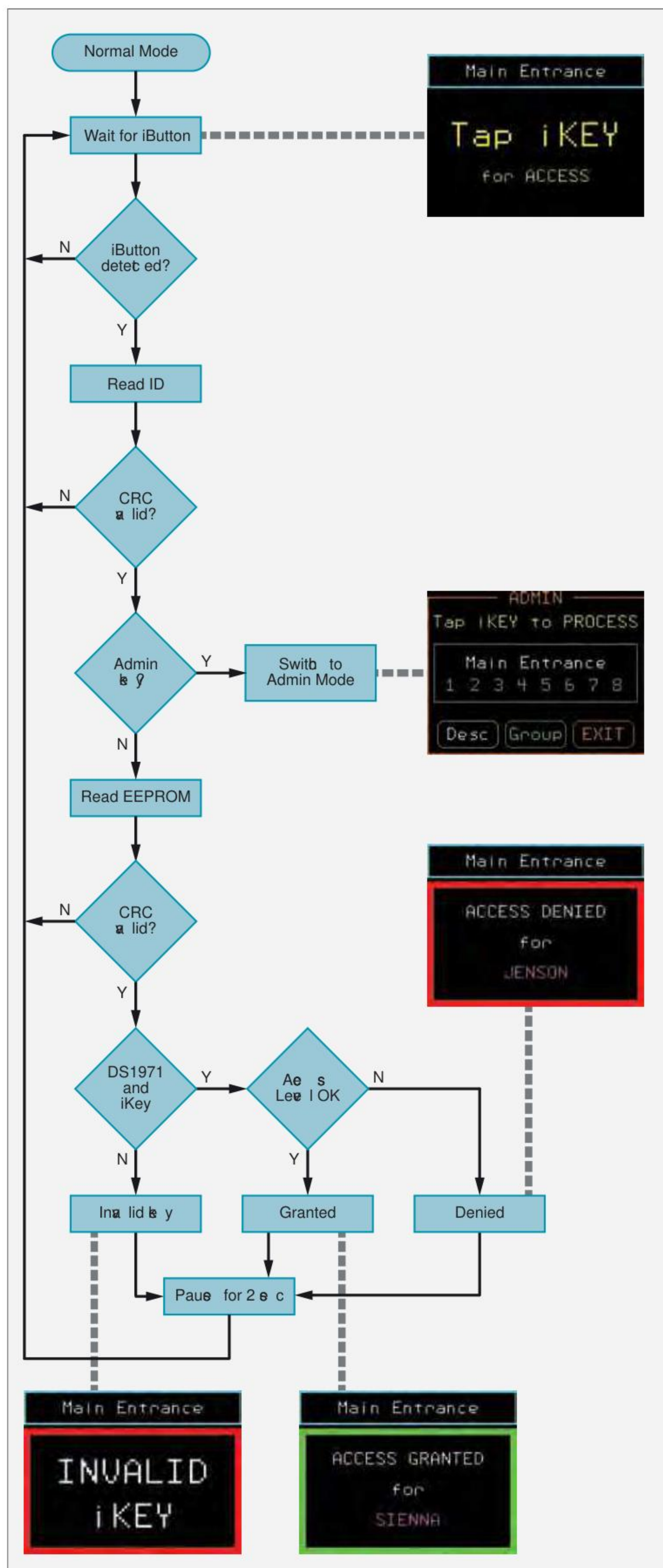


Fig.3. Process flow for *iEDL* Normal Mode.

- Admin Mode is automatically entered once the *Admin-Key* has been successfully defined
- To exit Admin Mode to Normal Mode, press the 'EXIT' button on the *iEDL* touchscreen.

The Power Up process flow diagram is shown in Fig.4.

Admin screen

When the *iEDL* is in Admin Mode, there are two main functions that can be performed: Reader configuration and iKey configuration.

The Admin screen (Fig.5) displays the current settings for the *iEDL's Description*, and *Access-Group-ID*, and also prompts the user to tap an iKey (if an iButton needs processing). At the bottom of the Admin screen there are three buttons: 'Desc', 'Group' and 'EXIT'.

Process Flow 3: iEDL Admin Mode (Reader config)

This section covers the reader configuration, which is how to alter the *iEDL's Description*, and/or the *iEDL's Access-Group-ID*.

- On pressing the touchscreen 'Desc' button, a pop-up touch-keypad appears (see Fig.6). The keypad enables a *Description* to be defined (ie, entered) for the *iEDL*. To be precise, it allows the current *Description* to be edited. Note that on first power up, this defaults to 'Micromite iEDL'. On saving the edited *Description*, it is stored in the Micromite's Flash memory (using the MMBASIC command: VAR SAVE Desc\$) and the user is then returned to the Admin menu
- On pressing the 'Group' button, one of eight possible buttons (numbered 1-8) are displayed. Pressing one of these buttons defines the *iEDL's Access-Group-ID* (and the value stored in the variable: AccessGrpID. This value is saved in Flash memory (using: VAR SAVE AccessGrpID), and the user is then returned to the Admin menu.
- On pressing the 'Exit' button, the *iEDL* will switch back to Normal Mode.

Process Flow 4: iEDL Admin Mode (iKey config)

This section covers how to process an iButton. There are several scenarios that can occur. For example, it could be to check an iButton (to see if it is configured or not), or to issue a new iKey, or to edit the configuration data stored in the EEPROM of an existing iKey.

On presenting an iButton in Admin Mode, it will be processed depending on the following:

- A blank DS1971 iButton has the option to be assigned to a user (via the touchscreen) – in other words, issue a new iKey
 - The keyholder's *Name* is entered via the pop-up touch keypad
 - The keyholder's *Door-Group-Access-Levels* value is entered on the touchscreen
 - on pressing 'Save', the user is prompted to tap the same iButton on the *iEDL's* iButton reader. If the same iButton ID is detected, then all the relevant data is written to the iKey's EEPROM. If a different iButton ID is detected, then a suitable message is displayed (with the option to Exit, or try again).
- An existing iKey (DS1971) can be wiped, or the configuration data can be changed (keyholder's *Name*, and/or their access permission) via the touchscreen in a similar way to issuing a new key
- If the *Admin-Key* is detected, the *iEDL* will simply display a message on the touchscreen stating that it is the *Admin-Key*.

Message box

Another useful feature (borrowed from Geoff Graham's *SuperClock*) is the pop-up message box. As commented in the program code, this handy routine draws a message box on the touchscreen, with an OK button. When a message needs displaying, this is used to halt the program, and it simply waits for the OK button to be touched, after which the program continues (see Fig.7).

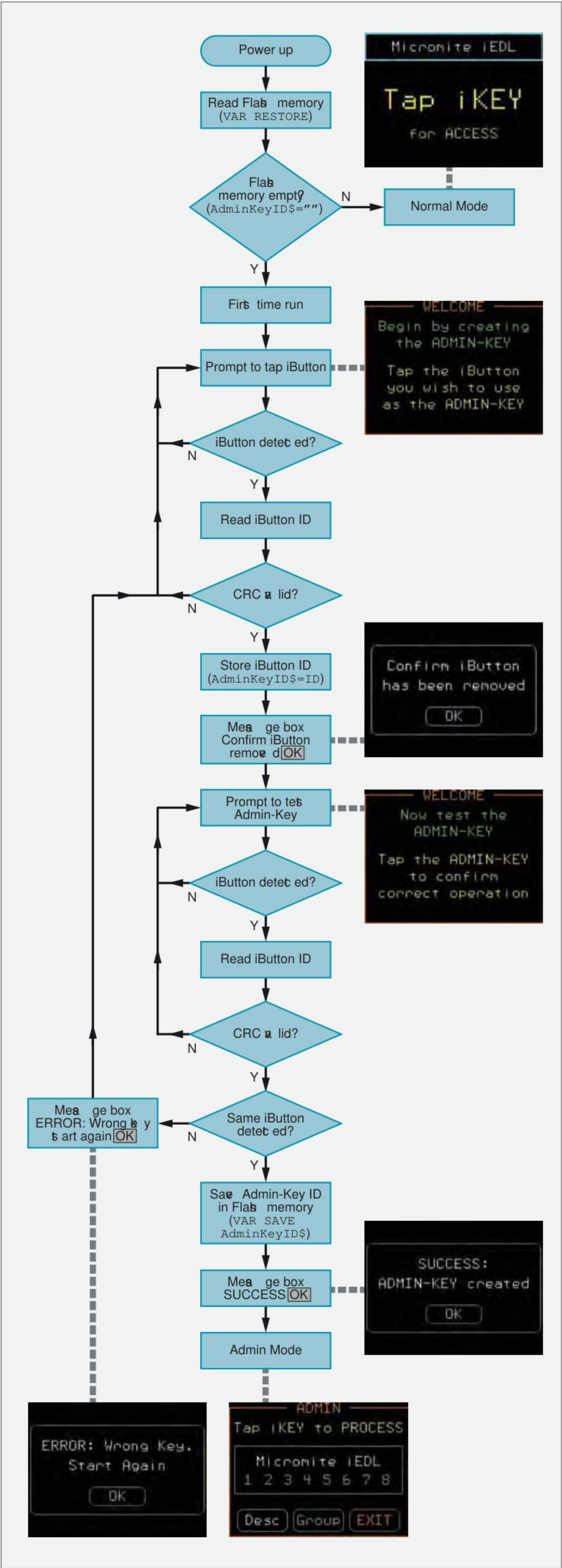


Fig.4. Process flow for Power Up.



(left to right) Fig.5. The Admin screen is used to either configure the *iEDL*, or to issue (and check) *iKeys*.

Fig.6. This pop-up keypad (adapted from Geoff Graham's *SuperClock* program) makes it possible to enter an alphanumeric description. In the *iEDL* software, it is used to enter an *iEDL Description*, and a keyholder's *Name* when issuing/editing an *iKey*. Note: the large left and right arrows navigate to different sets of characters (with 12 being shown at a time).

Fig.7. This pop-up message box (borrowed from Geoff Graham's *SuperClock* program) displays warning messages and effectively halts the program until the user clicks the OK button.

iEDL software

The *iEDL* software (*iEDL.txt*) can be downloaded from the June 2022 page of the *PE* website. Once installed, look through the code so you can compare it to the process flows provided above. We will not go into any further discussion here about how it works as the comments in the code (along with the process flow diagrams) should be easy to follow. Run the code and have a play.

At a minimum, you will need to have two *iButtons* and a single *iEDL* (but there's no need for a door complete with electronic door-locking mechanism!). At any time, you can stop the code (`Ctrl-C`) and examine what is going on. You should be able to work out how the program code works as a standalone system.

Ideas for customisation

As with any code supplied, we encourage you to make changes to it. This project allows for modification, so here are a few ideas to think about:

- Change the colours
- Alter the characters available, and/or the sequence they appear) on the pop-up touch-keypad
- Add a real-time clock (RTC) and display the date and time on the screen (in Normal Mode)
- Add automatic time-outs in the Admin screens so that the system doesn't get left in Admin Mode
- Increase the number of *Access-Group-IDs* to allow for more than eight groups (only sensible when more than eight doors need to be secured)
- Use the spare bytes in the *iKey* EEPROM to store some additional data
- Add a list of blocked keys in an *iEDL*.

I hope this has sparked some ideas of your own – remember, the best way to learn is to study and adapt the software.

We hope you have enjoyed this mini-project. Do contact us if you build an *iEDL* and let us know how you get on, and what modifications you may have made. And remember, if you get stuck, just reach out to us and we will do our best to help.

Next time

Unfortunately, the ongoing chip shortage has greatly affected the availability of many Micromite and Maximite products. However, another product that is readily available is the Raspberry Pi Pico (as featured in last month's *PE*). Not only is it available, but it is also extremely cheap (typically around £3.50). Wouldn't it be fantastic if a version of MMBASIC was available for the Pico? Well, we have some great news for you; MMBASIC is now available for the Pico, and next month we will show you how easy it is to get started. As an added bonus, the MMBASIC for the Pico is the Plus version, which provides many more features than the Standard version. And in case you're wondering, yes it can also control many of the Pico add-on boards that are currently flooding the market. So be prepared to be amazed next month when we show you everything you need to know to get up and running.

Until then, stay safe, and have FUN!

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1.2mH, 1.5mH, 2mH, 2.7mH, 0.5mH (tapped at 0.3mH) (each)	£5.85
LS3/5A transformer-core 15Ω assembled crossover board (each)	£60

Fully assembled and tested high-quality speaker prototypes – ask for details

LS3/5As and other similar speaker systems (pair)	£200-£350
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Fully tested reclaimed speakers

Vifa BC14 5-inch woofer (each)	£15
Vifa TC26 1-inch tweeter (each)	£15

Low-price speakers

Celestion elliptical 6x4-inch 5Ω (Robert's Radio)	£3.50
Philips 4-inch 4070	£2.00
EMI 10x6-inch, 30Ω Alnico	£10
64mm 64Ω neodymium	£1.20
3.5-inch 25Ω	£3.50
5x3-inch elliptical 50Ω or 80Ω Alnico	£3.50
1.65x2.75-inch 8Ω	£1.50

Can't see what you want? Just ask – we have a huge stock of inexpensive high-quality parts!

Capacitors

Note '10/63' denotes '10µF 63V'.

Polyester

3.3/100, 4.7/250, 4.7/63	£1.00
5.6/63, 8.2/63, 10/63	£2.00
Mullard 'Mustard' C296 0.22/400	£2.00

Polycarbonate

Axial 2.2/63 1%, 4.7/160, 6.8/63	£1.00
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Radial

6.8/160V, 10/63	£2.00
Reclaimed 22/63	£2.00

Polystyrene

Philips 1% 4.7nF/160, 6.2nF/500, 12nF/63, 22nF/63, 110nF/63	£1.00
RIFA 1% 100nF/100	£2.00
Suflex 2.5% 10nF/63 (rad. or ax.)	£0.50

Radiation resistant

Siemens cellulose acetate MKL 2.2/25	£0.80
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Electrolytic – Mullard blue 017 series

10/25, 22/25, 100/10	£0.50
150/40, 470/40, 1000/40	£1.00

Tantalum – metal cased

22/50, 47/35, 68/25, 100/20, 120/10, 150/16, 220/10, 330/6	£2.00
22/35, 33/35, 47/20, 68/15, 100/10, 150/6	£1.25
4.7/50, 6.8/35, 10/25, 10/35, 22/15	£1.00

Moulded-case tantalum

Kemet axial 6.8/10	£0.30
Kemet radial 33/10	£0.40
STC radial 100/20	£1.50

Tantalum bead

22/50	£1.00
470/3	£2.00
680/6.3	£3.00

Wet tantalum

220/25 axial	£3.20
Castanet button 140/30, 470/3	£3.20
Hughes 540/10	£3.20

Bipolar

Hermetic bipolar tantalum 16/35	£3.20
Callins Elcap wet aluminium 10/50	£0.50

Philips solid-aluminium (axial) 121/123

47/16	£1.00
330/6.3	£2.00
100/35	£4.00

Philips Pearl 122 series (radial)

10/16	£0.30
10/25	£0.50

Silvered mica (radial)

4.7nF/500 5%	£1.00
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Trimmer capacitors

Vishay plastic-film 4-40pF	£0.80
Vishay plastic-film 5.5-45pF	£1.00
Vishay plastic-film 5-80pF	£1.20
Vishay plastic-film 10-250pF	£2.00
Mica 1-12pF, 2-40pF	£1.00

Audio transformers and inductors

Eagle transformers

LT44, LT722 driver, LT700, LT723	
500Ω output	£2.50
LT30 500mW output	£3.50

Repanco

T/T3 splitter transformer	£4.00
CH2 5mH RFC	£2.00

Balanced output transformer

Vigortronix 600Ω VTX-101-007	£10
Vigortronix 600Ω VTX-101-3001	£10
Vigortronix 600Ω VTX-101-3002	£15
Gardners 150Ω	£10
Reclaimed BBC LL74/MPC nickel core 600Ω	£12

Reclaimed mic input transformer £15

Inductors

82µH, 4.7mH, 100µH, 270µH	£2.00
7-inch ferrite rod with MW and LW windings	£3.00

Special resistors

Bourns wire-wound trimmer 5kΩ	
3059 JM panel-mount	£2.00
Thermistor RA53, A13	£4.00
Thermistor CZ1, CZ6	£1.50
Holco H2 2.2MΩ 1W, 1%	£1.00
Welwyn 1GΩ 2W	£1.00
Allen Bradley 1.2kΩ 2W C-comp	£1.00
Lots of big valve resistors available.	

Potentiometers

Bourns 81

25kΩ lin cermet	£2.00
25kΩ lin conductive plastic	£3.00

Plessey moulded-track

5kΩ log with switch	£3.00
50kΩ A/log	£3.00
Mil 250kΩ lin dual	£5.00

Alpha

16mm 4.7kΩ A/log	£0.80
220kΩ A/log	£0.80
10kΩ lin centre-detent dual-gang	£1.50

Allen Bradley J series/Honeywell

10kΩ lin 1 million cycles	£5.00
Blore Edwards AB 45 dual 5kΩ A/log with switch	£3.50
Alps RK9 dual-gang 5kΩ RD law	£4.00
BI P260 500kΩ log conductive plastic 1 million cycles	£3.00
Colvern wire-wound 100kΩ or 50kΩ dual-gang 3W	£8.00
Mil Spec hermetic 10Ω	£8.00

Miscellaneous

Theremin Clearance Sale!

Elysian Theremin MIDI box	£300
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PCBs

Pocket Theremin (EPE, 1996)	£4.00
Elysian Theremin (EPE, 1996)	£12
Synth VCF, VCO (EPE, 2017)	£3.00
48V PSU (EPE, 2019)	£3.00

Relays

STC hermetic 4190 24V DPDT	£4.00
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Switches Blore Edwards/Plessey

MH1 4-pole 3-way	£3.00
Elma 01 2-pole 6-way	£6.00
3PDT guitar pedal stomp switch	£2.50

Valves

EC88, PCL84	£3.00
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Robert's Radio modules

Tuners LP1169, LP1179	£7.00
IF strip LP1171	£7.00

Knobs – large Bakelite

Bulgin 1960s and Sifam 1970s	£1.50
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Contact

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Llandrindod Wells, Powys
LD1 5HE (visit by appointment)
+44 (0)1597 829102
jrothman1962@gmail.com

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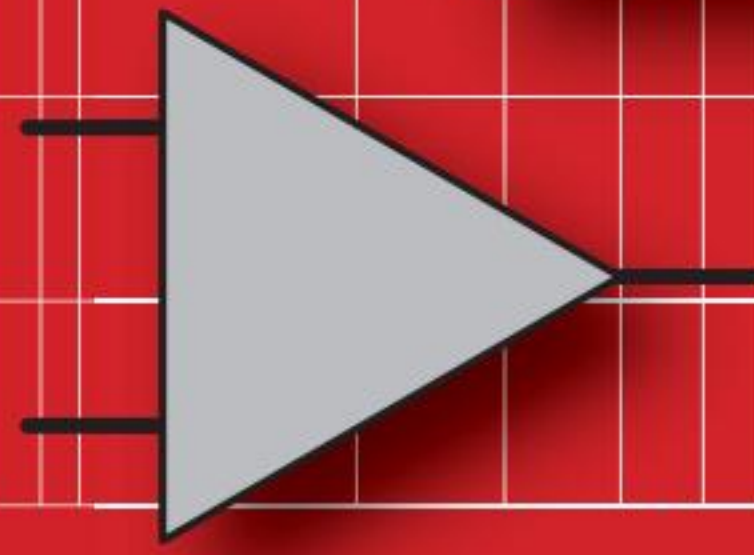
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AUDIO OUT



By Jake Rothman

New de-thump circuit and power supply mods

Most audio circuits make nasty noises ('thumps') when they are turned on and off as power rails and DC conditions stabilise. Although it is possible with great care to make quiet circuits, it is usually expedient just to mute the output during the stabilisation periods. This muting is normally accomplished by means of switch out the audio output, most commonly a set of relay contacts.

Some low-cost circuits have a pair of transistors to short out the audio output, possibly more reliable than a relay, but giving higher output impedance and distortion. Whatever approach is taken, these switches have to be controlled with a timing sequence generated by a special circuit to successfully mute potential thumps.

In last month's *Universal Audio Power Supply* there was a relay driver circuit for audio output muting. I designed this circuit, shown in Fig.1, in 1984 for a college project. Although it's done the job perfectly well in my products for nearly 40 years, it seemed worth revisiting, since there's no circuit that can't be improved with regard to reliability, function and power consumption. Here, I'll show some of the design processes involved in this rather obscure branch of audio circuitry. Finally, I'll give some extra tweaks to the power supply itself.

Original circuit

The basic function blocks of a relay muting circuit are shown in Fig.2. The requirement is a few seconds delay in turning the relay on at power-up and instant turn-off when powered down. First, there is a rectifier and a minimally sized smoothing capacitor to facilitate quick discharge when turned off. Then there comes an RC timing circuit (R4, C2). This drives a Darlington transistor (TR2 and TR3) to power the relay. Following that are some refinements, mainly the addition of a timing capacitor discharge circuit (TR1) to deal with a turn-off (possibly, quickly followed by a turn-on again). This is basically a reset function so that a full turn-on delay period is always available. Another circuit dodge is the 'current saver' circuit in series with the relay. This consists of a big electrolytic capacitor (C3) in parallel with a high-wattage resistor (R7) giving a full voltage pulse to pull the relay in. The voltage then drops to a value sufficient to just hold the relay, resulting in half the pull-in current set by the resistor. This function is shown in the graph in Fig.3. The key point here is that it takes less voltage (and hence current)

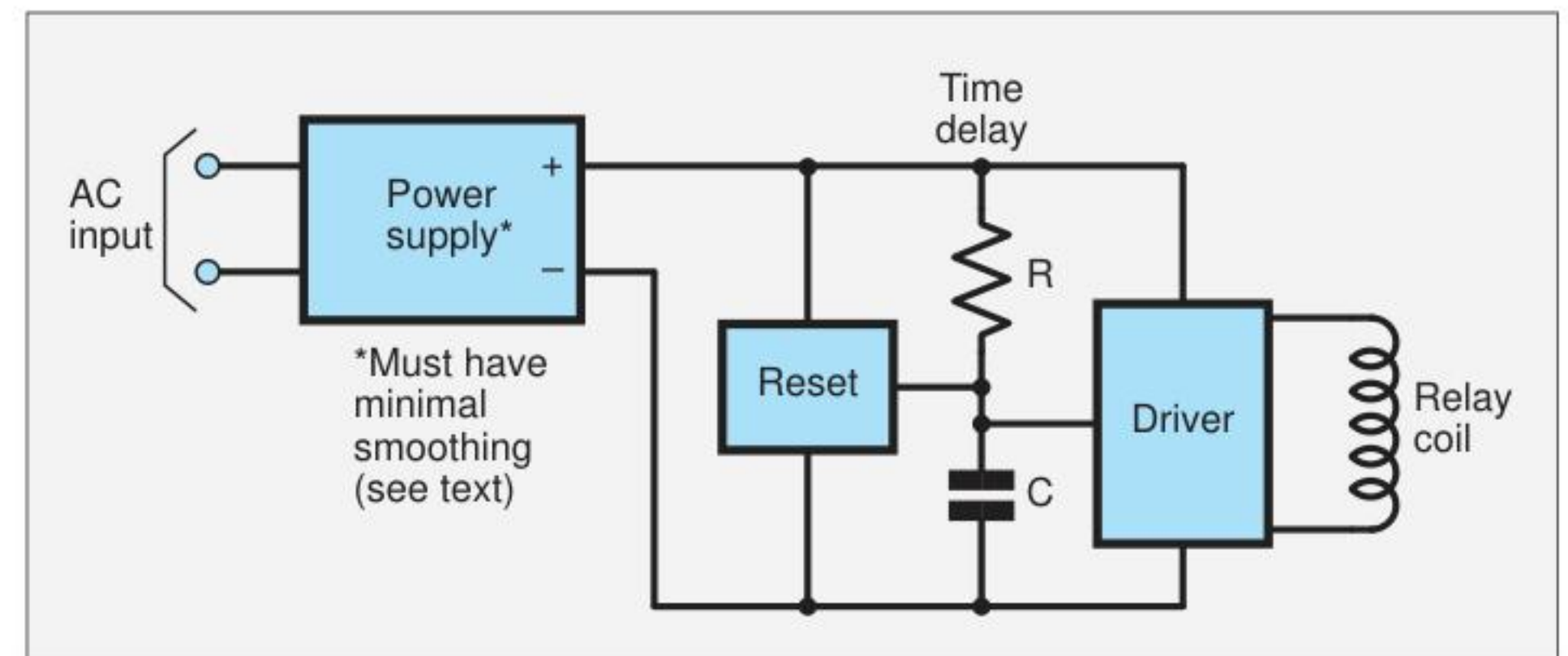


Fig.2. Block diagram of a typical de-thump circuit.

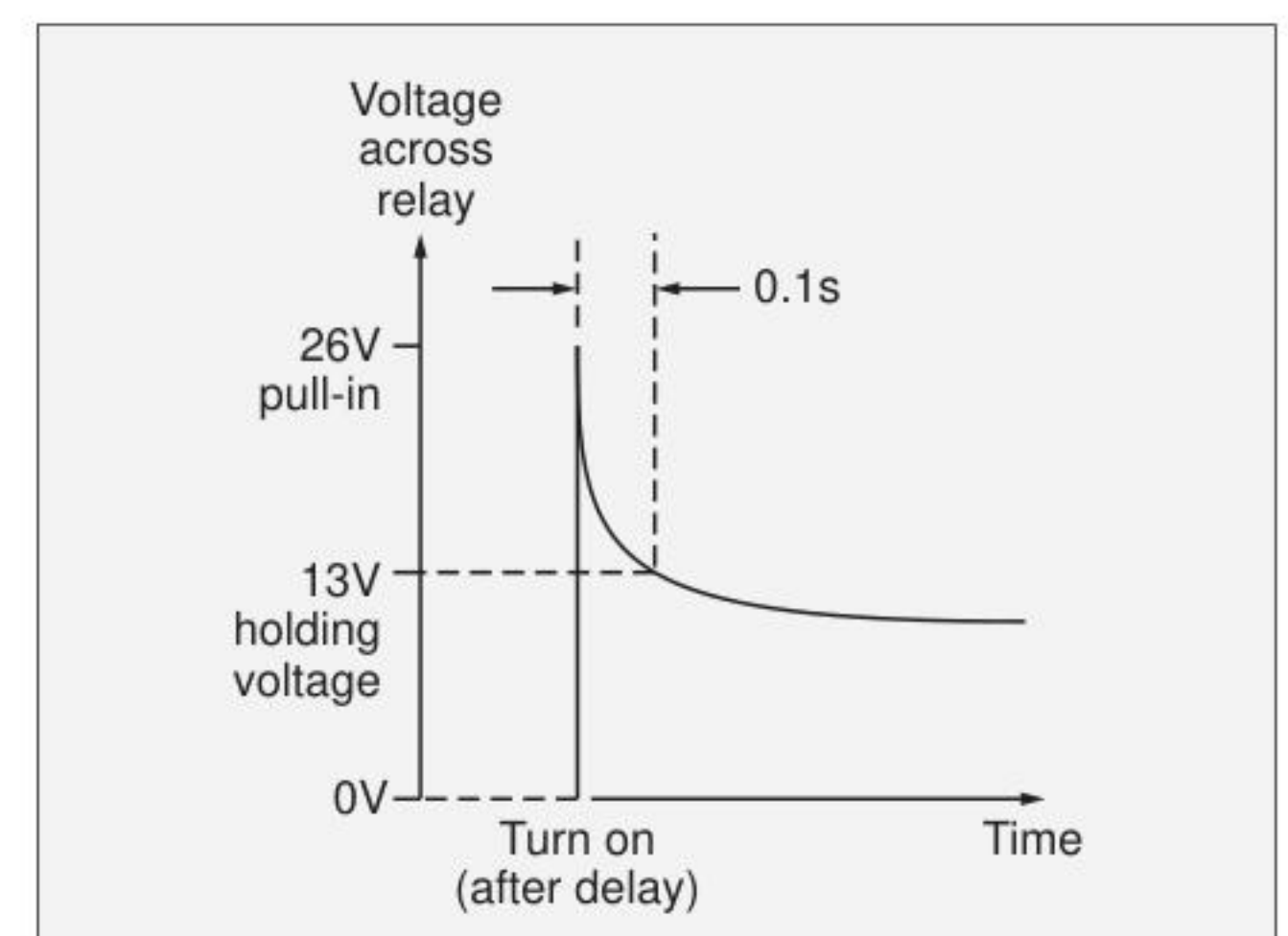


Fig.3. Graph showing pull-in and hold voltages used for a 24V relay.

to *hold* a pulled-in (switched-on) relay than to *switch* it.

Improvements

The main weakness in the original circuit was the slow turn-on time, which resulted in less than expected performance from the current-saver. A current-saver circuit needs a fast switch-on step to deliver a good kick to the relay and pull it in decisively. This was achieved by putting in a comparator built around a 741 (IC1) after the timing circuit. This improvement enabled the holding voltage to be reduced from 21V to 13V, resulting in a relay current reduction from 30mA to 18mA. The comparator's output was sufficient to drive the

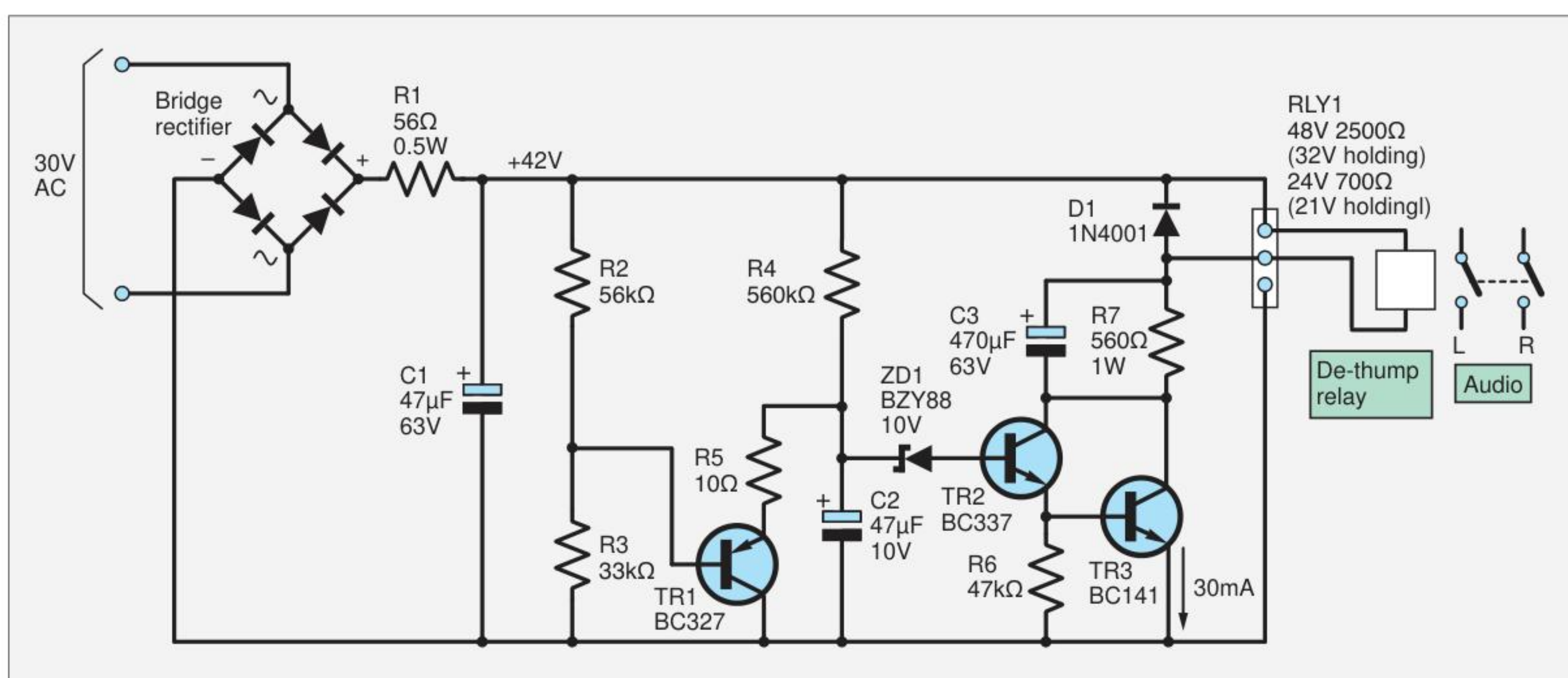


Fig.1. My original, 40-year-old de-thump driver circuit.

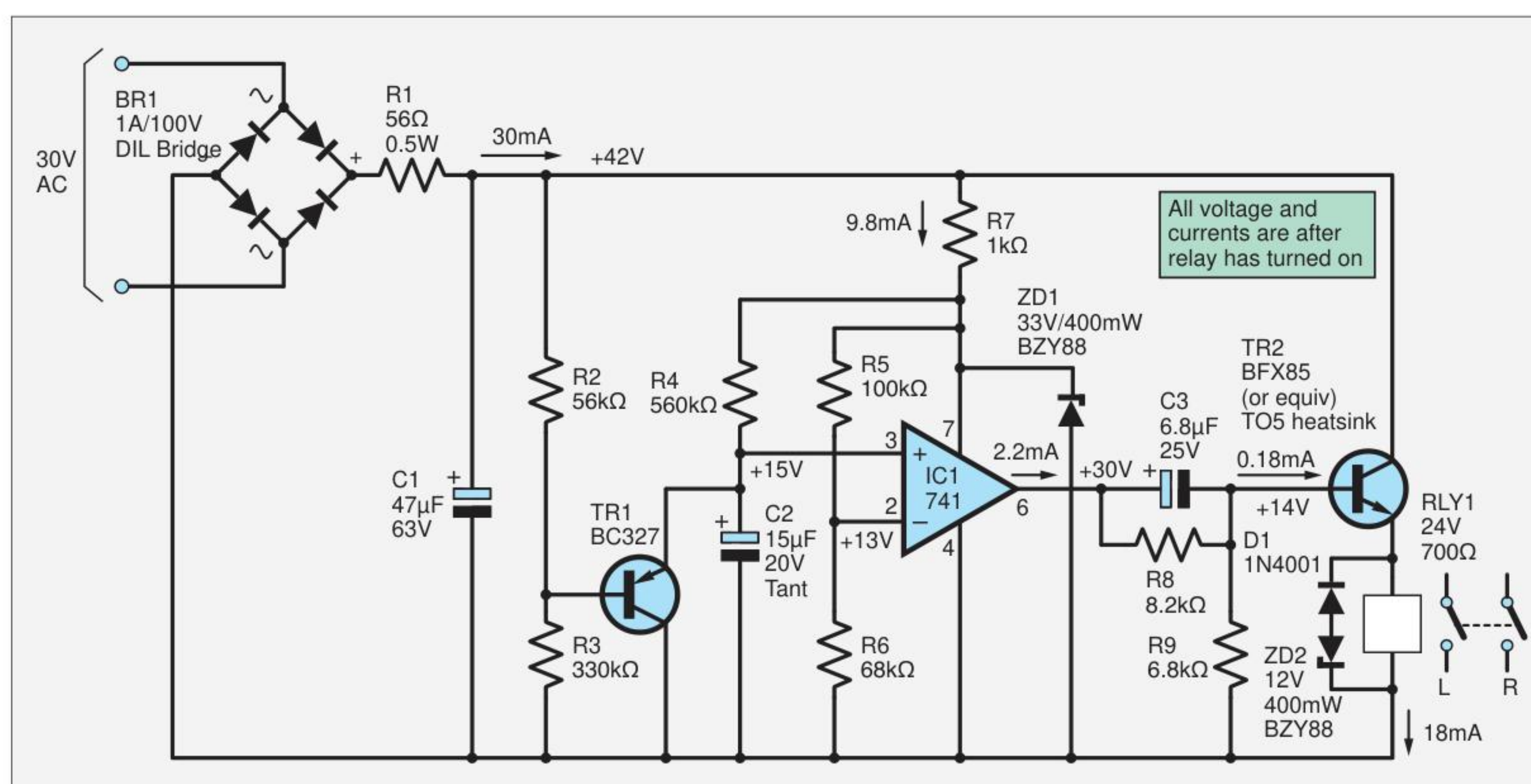


Fig.4. Improved de-thump circuit using bipolar devices.

output transistor directly without an intervening driver transistor (TR2 in Fig.1). The op amp must have a simple 33V Zener regulator to protect it from over-voltage. (The power rail is 43V, while the op amp's rated maximum is 36V). An unexpected benefit of this arrangement was the hum level on the relay coil was reduced by a factor of five, down to 500mV_{pk-pk}. This may help in low-noise applications. (I'm not sure how much hum can couple from the relay coil into the signal switches. This possible crosstalk path may be worth further investigation.)

Another improvement was to position the current-saver circuitry on the input of the relay transistor rather than its output, getting rid of the bulky and unreliable 470μF electrolytic capacitor (C3 in Fig.1). This new bipolar-based circuit is shown in Fig.4. The high-wattage resistor (R7) is also removed, although its voltage drop and the 500mW dissipation is now transferred to TR2, the output device.

Back-EMF protection

When the relay turns off, protecting the output device from the back voltage as the magnetic field collapses is usually done by a single diode. However, this approach slows down the release time of the relay while the back current circulates. If the back EMF is clamped at say 12V by a Zener (D2) rather than the 0.7V of a normal diode (D1), then the energy is dissipated faster, resulting in a quicker release.

FETishisation

A standard trick I use to improve old circuits is to replace bipolar devices with FET-based devices. Their higher input impedance means lower drive currents. This minimises power consumption and allows capacitor sizes to be reduced.

Relay driver

The first thing to do is to replace the bipolar transistor (TR2, Fig.4) with a MOSFET. The drive current required is then reduced from about 2.3mA to

virtually nothing. This allows a low-power op amp to be used for IC1. The TL061 is ideal for this job, because it has FET inputs (often the Texas trade name 'Bi-FET' is used). Therefore, the loading on the timing circuit is minimal, allowing the resistor to be increased and the capacitor size reduced. This saves cost, since low-value (<4.7μF) tantalum capacitors are cheap.

Now that the currents are reduced, the current-saver circuit impedance can be scaled up, allowing the electrolytic capacitor (C3)

to be replaced with a non-polarised type – always a good idea. Also, the Zener regulator current can be decreased by increasing R7 to 5.6kΩ, allowing a reduction in current to the comparator circuit from around 10mA to 2mA. The total current consumption is now 20mA, rather than 30mA for the original circuit.

Since a large TO220 metal-tab MOSFET consumes no more drive current than a small type, this avoids the need for a clip-on heatsink which the bipolar transistor required. If a TO220 bipolar transistor, such as a TIP31 were used, then the H_{fe} would be low, requiring more drive current than the TO5 type.

Discharge circuit

One of the characteristics of JFETs is that they are 'on' (conducting) when they have zero bias voltage on the gate. This characteristic is useful for the discharge circuit. The original PNP transistor configuration used couldn't fully discharge the timing capacitor; it stopped at about 1.5V. The JFET allows

it to fall all the way to 0V, making the operation of this circuit with repeated turning on and off more reliable. JFETs do cost more than bipolar transistors, but the P-channel J175 is still cheap and has a low on-resistance.

Final circuit

The final FET-based circuit is shown in Fig.5, and the Veroboard construction in Fig.6. For higher input voltages, R1 will need to be increased and the relay may be increased to 48V. No high-quality components are needed, generic parts will work

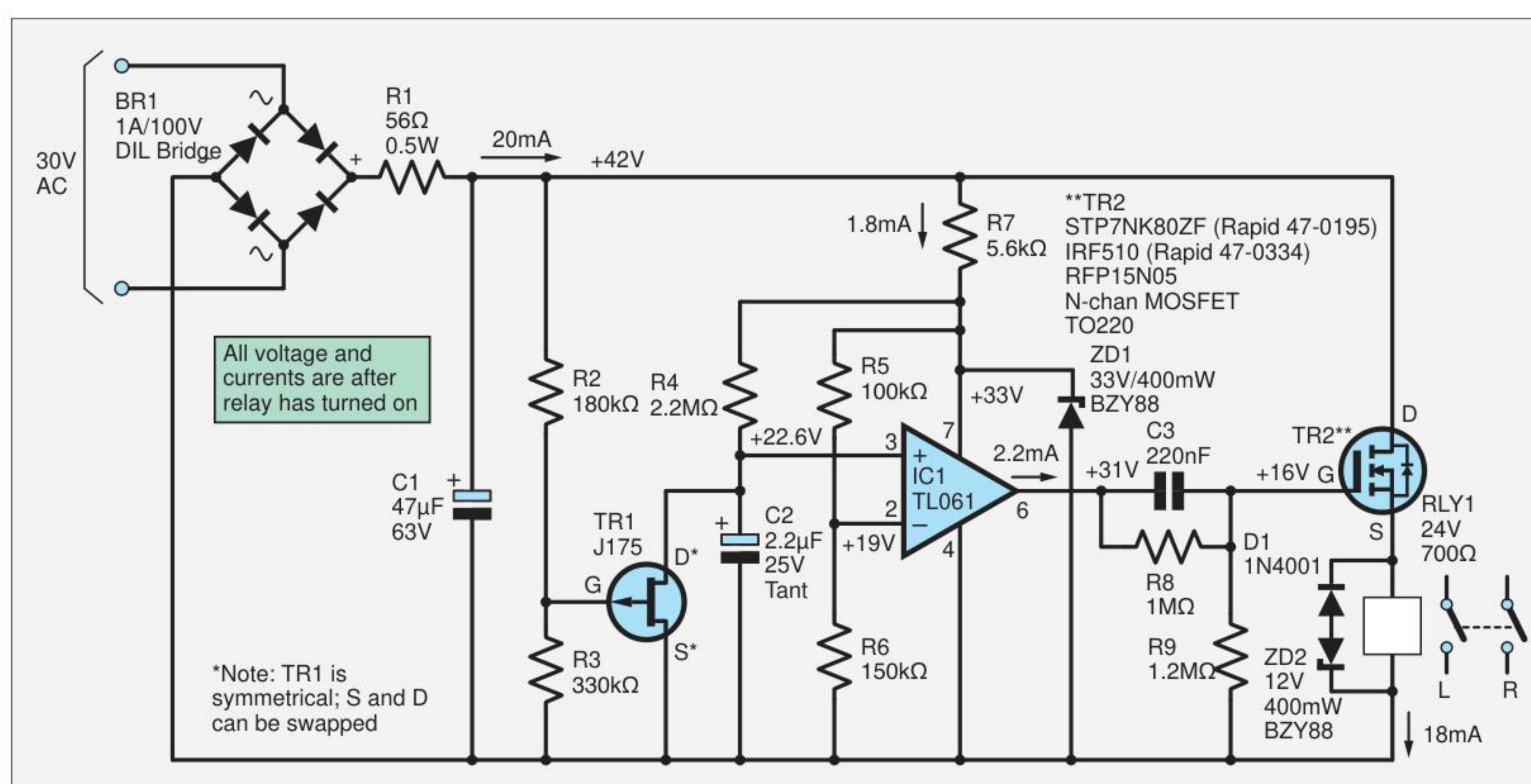


Fig.5. Final FET version of Fig.4 de-thump circuit, giving reduced power consumption and faster reset.

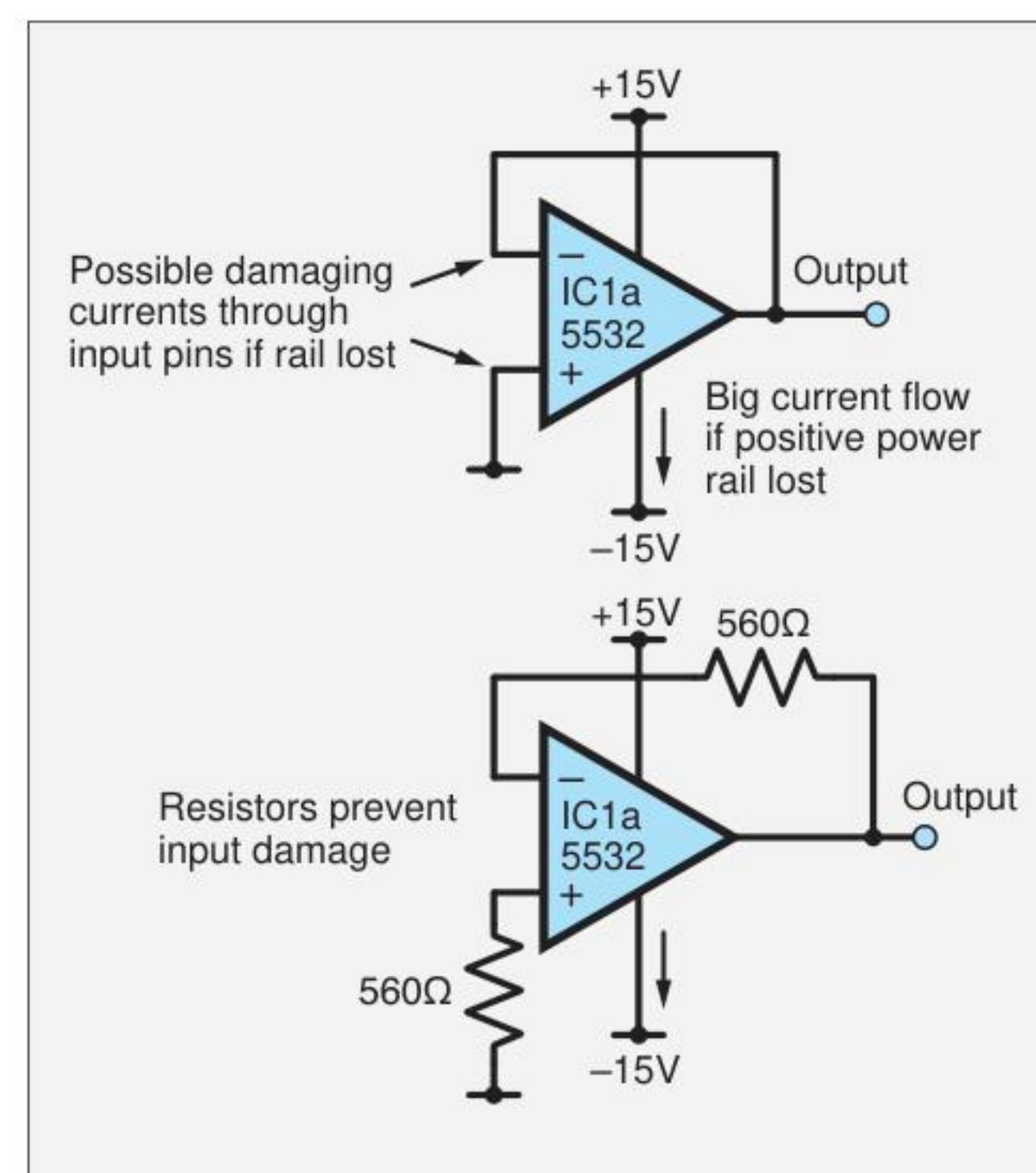
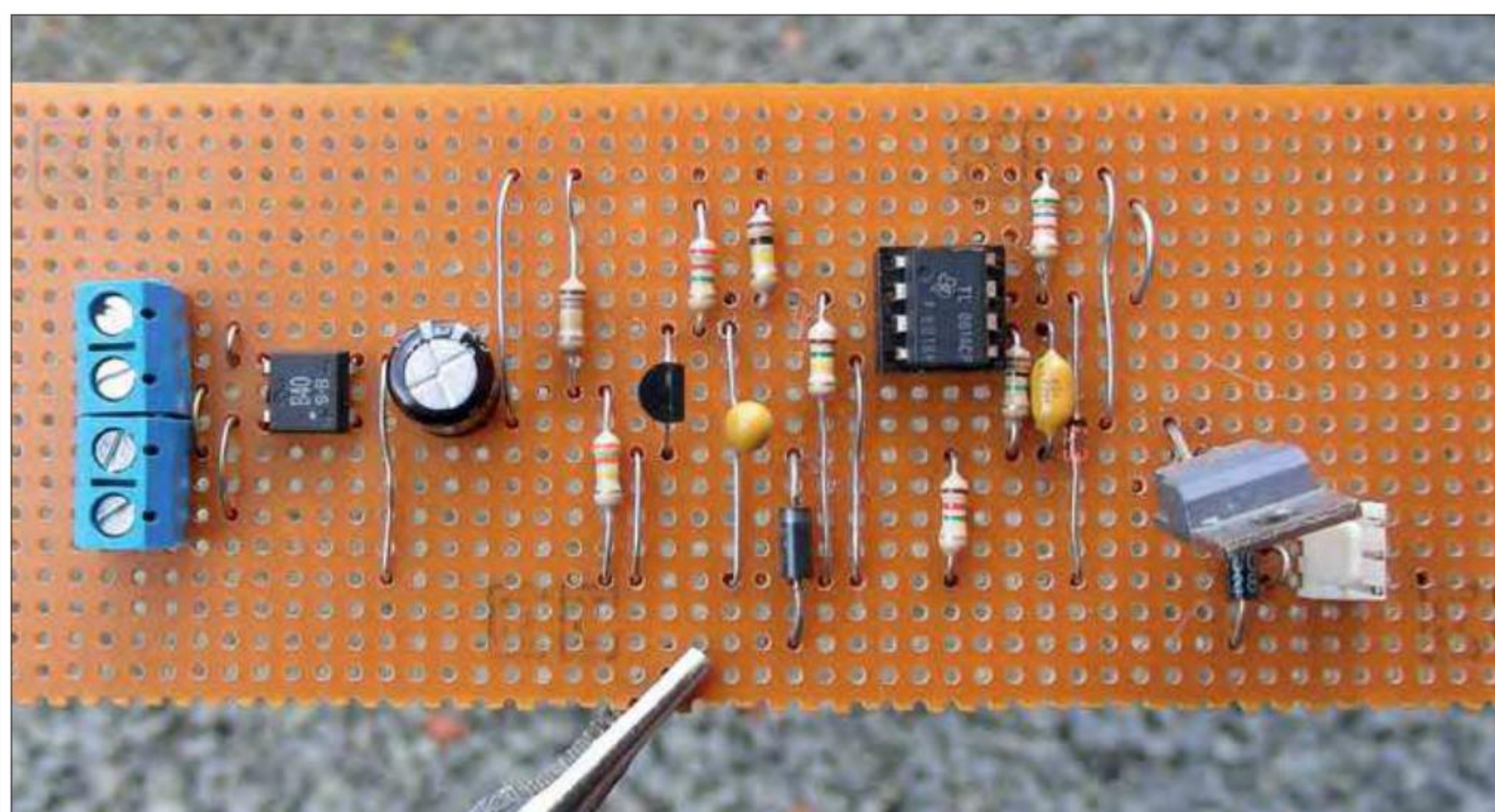


Fig.6. The de-thump circuit from Fig.5 constructed on Veroboard for testing. Layout is uncritical, and many experienced constructors can build it straight from the circuit diagram. If you don't mind waiting, a PCB is in preparation.

fine. The high input impedance of TR1's gate makes an ideal control input to connect a circuit to detect dangerous DC offsets on a power amplifier's output. However, this feature is for another day and another PCB design.

Component list

(Final version – Fig.5)

Semiconductors

- IC1 TL061 low power BiFET single op amp
- TR1 J175 P-channel JFET (Mouser part number 512-J175D26Z)
- TR2 I used an RFP15N05 N-channel power MOSFET, but any equivalent >50V >1A >1W free-air rating, such as STP7NK80ZF (Rapid 47-0195) or IRF510 Rapid (47-0334) will work.

- D1 1N4001
- ZD1 33V 400mW BZY88CV33
- ZD2 10 to 18V 400mW BZY88CV12
- BR1 1A 100V DIL bridge rectifier DB102 Rapid 47-2962

Capacitors

- C1 47μF 63V electrolytic
- C2 2.2μF 25V tantalum
- C3 220nF non-polarised, you can use any dielectric

Resistors

All 5% 0.25W carbon-film

- R1 56Ω
- R2 180kΩ
- R3 330kΩ
- R4 2.2MΩ
- R5 100kΩ
- R6 150kΩ
- R7 5.6kΩ
- R8 1MΩ
- R9 1.2MΩ

Miscellaneous

Connectors, Molex or screw
Veroboard 125mm x 55mm or bigger
Relay, 24V 700Ω

Further power supply add-ons

Mutual rail shut-down

Another useful enhancement to the power supply – and any dual-rail power supply – is mutual rail shut-down. This functions by turning off the other rail if one rail is shorted out or goes down for some reason. Occasionally, op amps and circuits can fail if one rail is lost. The audio engineer's favourite op amp – the NE5532 – is especially prone if it loses its positive rail, while still having a full negative rail, as shown in Fig.7. This is particularly bad in voltage follower circuits, where there is a direct connection from the output to the negative input. Also, this can be made worse if the non-inverting input is directly grounded. The total current can exceed 24mA in these situations, possibly exceeding the package dissipation (780mW for the SOIC8 pack, 1.2W for the DIP). This is why prudent designers put 560Ω resistors in series in these connections. Other circuits with low-impedance DC-coupled loads, such as distortion-cancelling transformer drivers and power amplifiers can even burn up. Also, in AC-coupled circuits, electrolytic capacitors can become reversed polarised, causing electrical damage and physical liquid leakage.

The original Soundcraft mixer power supplies had mutual shut-down, but used two positive LM338

Fig.7. Losing the positive rail can cause the NE5532 op amp to self-destruct.

regulators. I modified the circuit to work with positive and negative regulators, but the principle is the same; using the variable voltage feature of the regulators to reduce it to the minimum using transistors to pull the adjust pin to ground. This drops the output voltage to 1.6V, which is almost off, and certainly enough to provide protection. The circuit is shown in Fig.8.

Power rail symmetry

I don't normally like trimmers, but it can be advantageous with some systems, such as synthesisers, to be able set exactly symmetrical power supplies. It is possible, under worst-case tolerances, for the power supply outputs shown in Fig.8 to be +14.2 and -15.8V. With op amp circuits it's generally not the total magnitude of the voltage between the positive and negative rails that matters, but how equal they are. The good thing is, we only need one trimmer for symmetry, rather than two (one for each rail). Of course, this means you could end up with a ±14.5V or ±15.8V power supply, rather than the theoretical ±15V, but usually the quality of the balance outranks the actual voltage value of the outputs. Fig.9 shows the

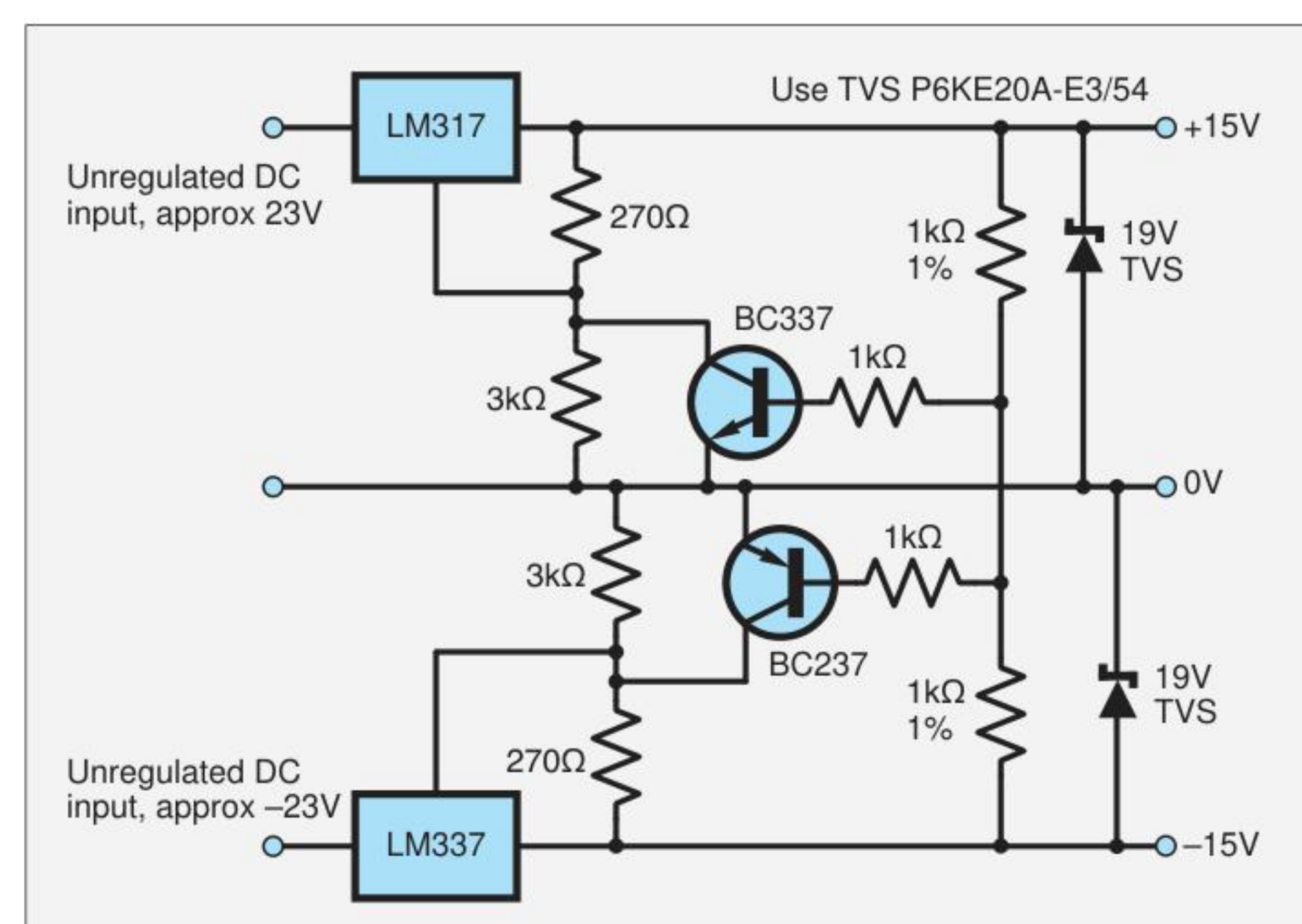


Fig.8. Mutual-rail shut-down circuit.

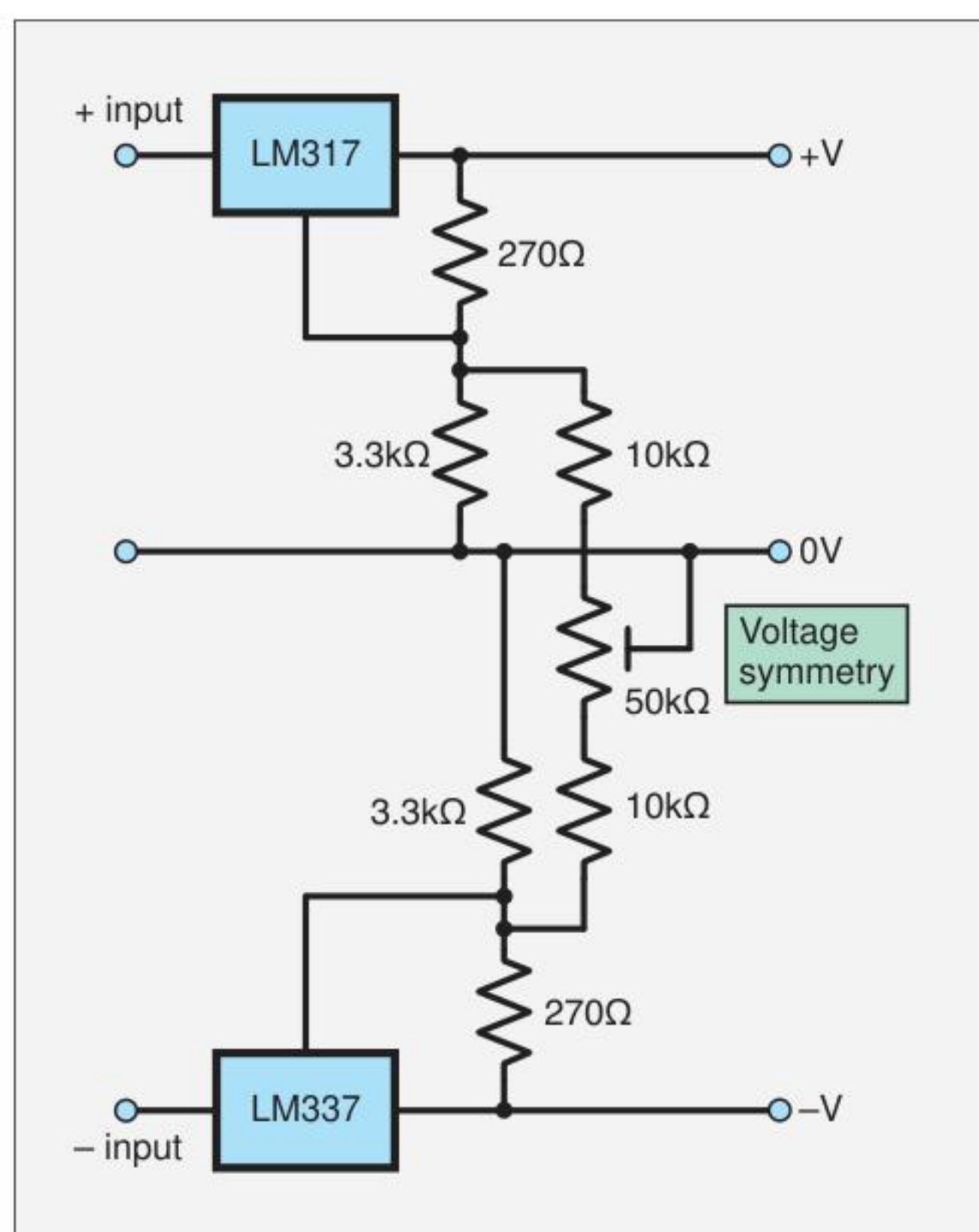


Fig.9. Power rail symmetry trimmer circuit – tweak to make the rails equal.

trimmer circuit. Note that the 3kΩ resistors (R7 and R8) have to be increased to 3.3kΩ to compensate for the parallel resistance of the trimmer network.

Building the add-ons

The shut-down circuit and the symmetry trimmer circuit can be built up together on the same bit of stripboard, as shown in Fig.10. Five wires go from this to the main power supply board.

PTC/polyswitch fusing

As mentioned last month, the LM317/337 short-circuit and over-temperature protection is a bit slow to react. The mains primary fuse can also be slow and possibly be changed by the user to one that has too high a current value. In view of this, it's well worth adding extra protection in the form of positive temperature coefficient (PTC) self-resetting fuses in the transformer secondary AC lines. This also helps with the mutual shut-down, because the transistor circuit (Fig.8) will only work assuming the regulators are fully functional. If a regulator has an input/output short the mutual shut-down

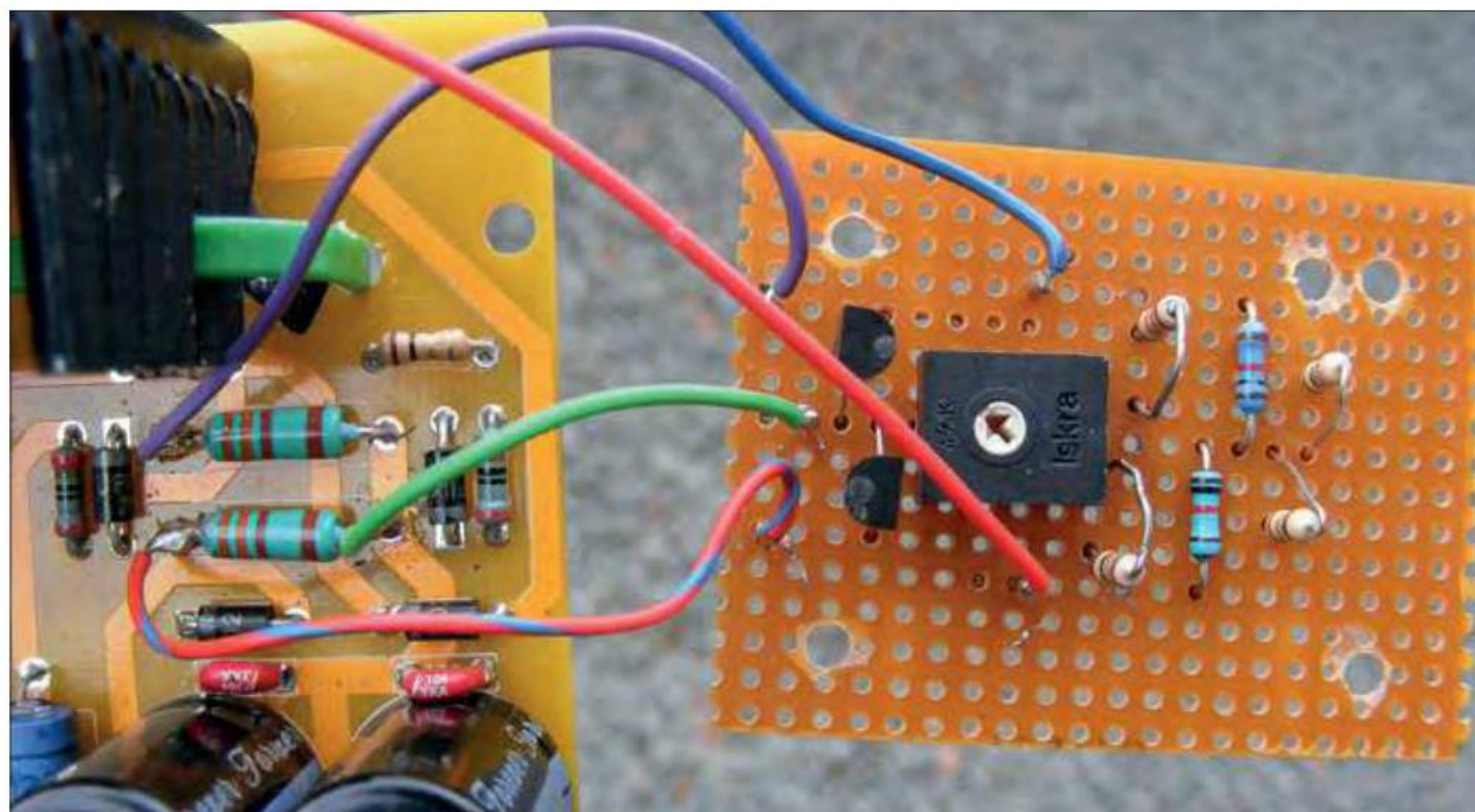


Fig.10. Shut-down circuit and rail symmetry trimmer board.

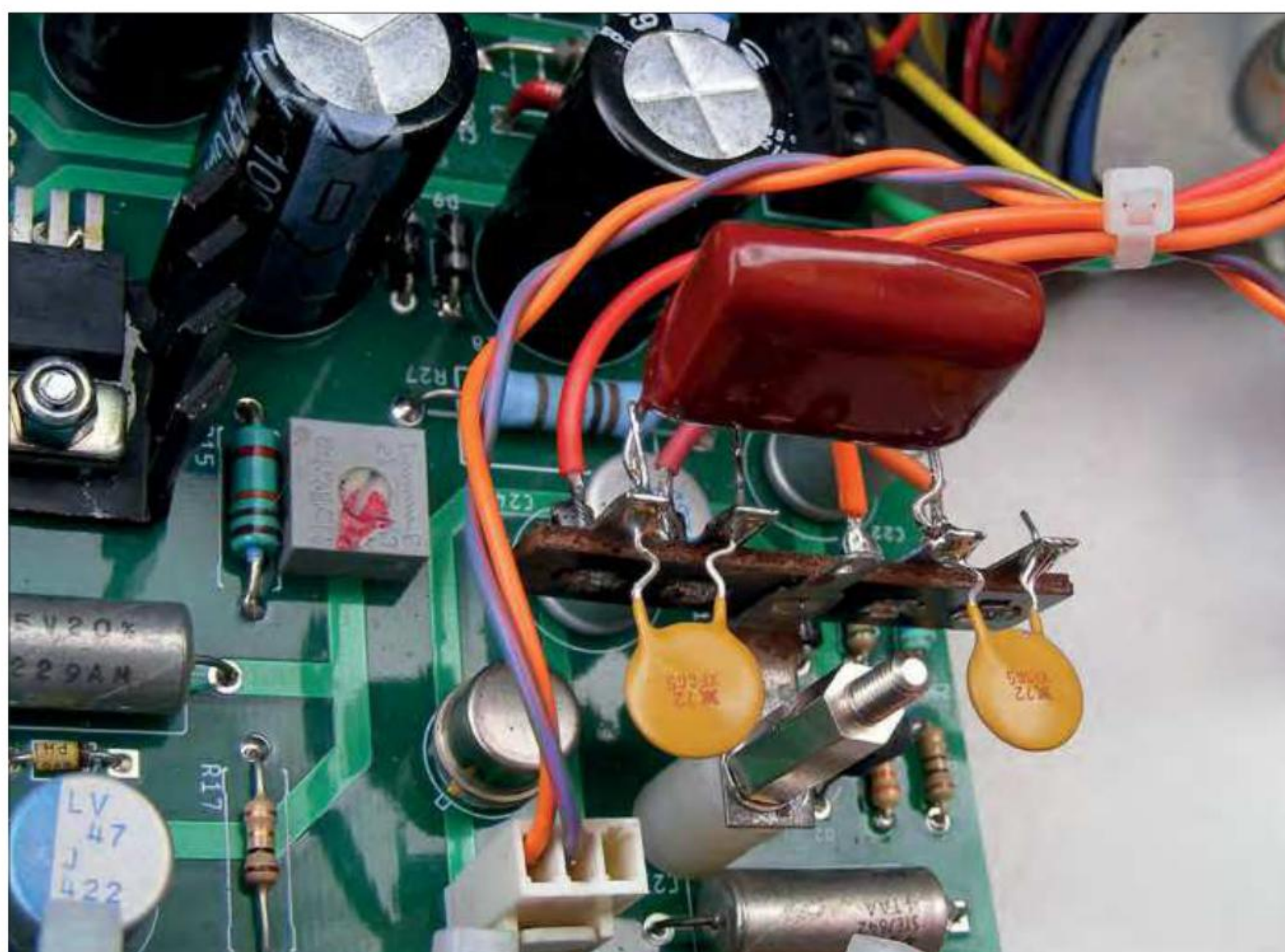


Fig.12. Suppression capacitor and polyswitch fuses added to transformer secondaries.

won't work. I chose the 0.5A Raychem Littlefuse RXEF050 (Rapid 26-0720). Using big heatsinks for the regulators, the 0.65A RXEF065 also works. It's worth spending 50p to protect a £20 transformer.

diodes or Transorbs across the output. A Vishay unidirectional transient voltage suppressor (TVS) diode P6KE20A-E3/54 (RS 811-9981) with a 19V breakdown voltage and 500W transient capability will fit in the holes for the 1N4001 start-up diodes, D20 and D21. When conducting these will trip the PTCs. A 40p upgrade that could save 20 op amps.

Fine tuning

The switching of the rectifiers can cause 100Hz modulated bursts of ringing in the transformer (discussed in the *Theremin Power Supply* article: PE, August 2020). This can be damped down by placing a parallel capacitor after the PTCs, tuned for the transformer used, as shown in Fig.11. A photo of this arrangement is shown in Fig.12.

That's all for now, and it just goes to show a circuit is never finished, only improved. Next month is a total wind up – I'll be looking at audio transformers!

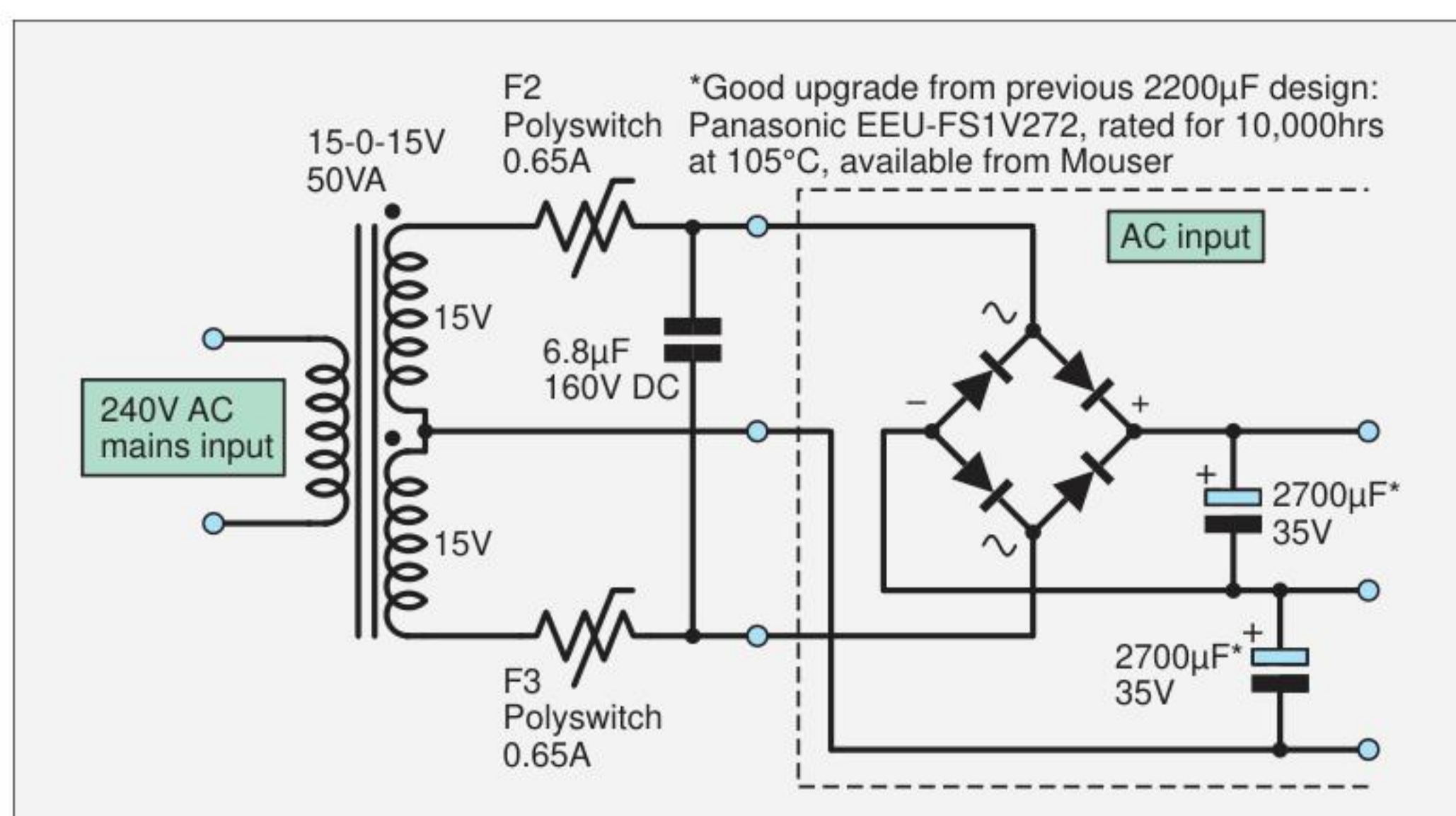


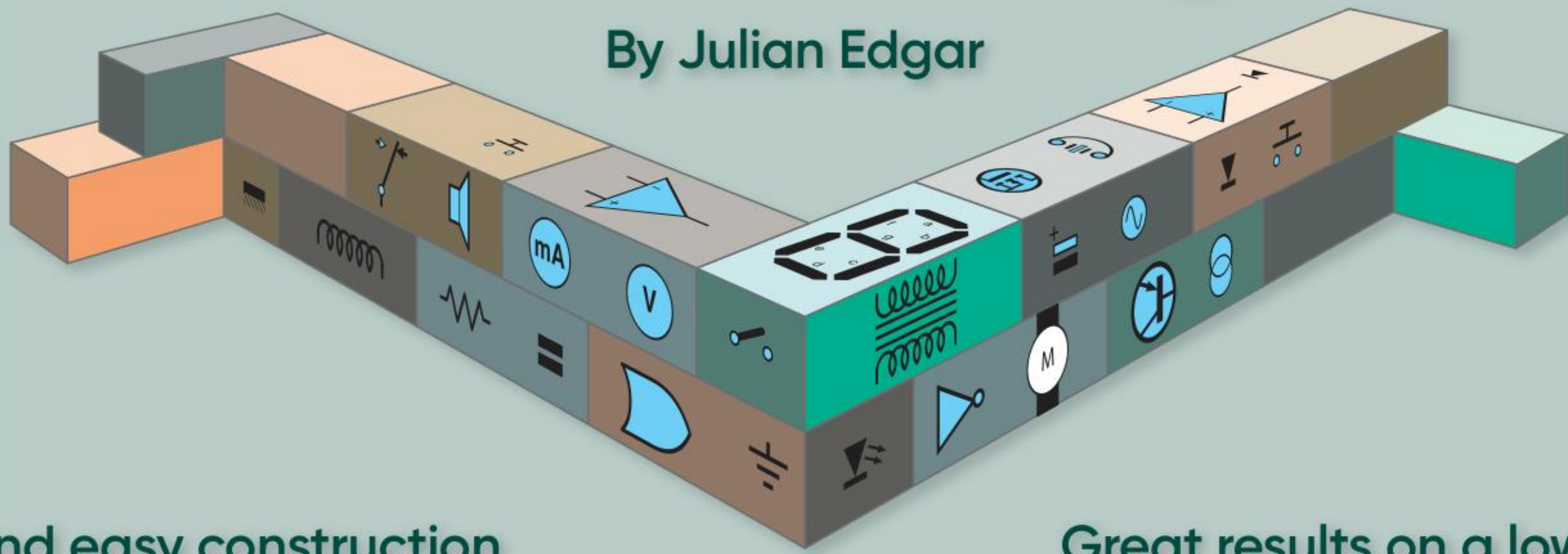
Fig.11. Inserting polyswitch fuses and adding an anti-resonance capacitor to the transformer. The optimum capacitor value depends on the transformer. For most toroids, 1 to 6.8μF 160V does the trick.

Overvoltage

When a regulator fails, like most semiconductors, it often becomes a short circuit. If this occurs from input to output, the high unregulated input voltage will appear on the output and possibly destroy anything connected due to overvoltage. A sensible precaution is to place high wattage (5W) 20V Zener

Electronic Building Blocks

By Julian Edgar

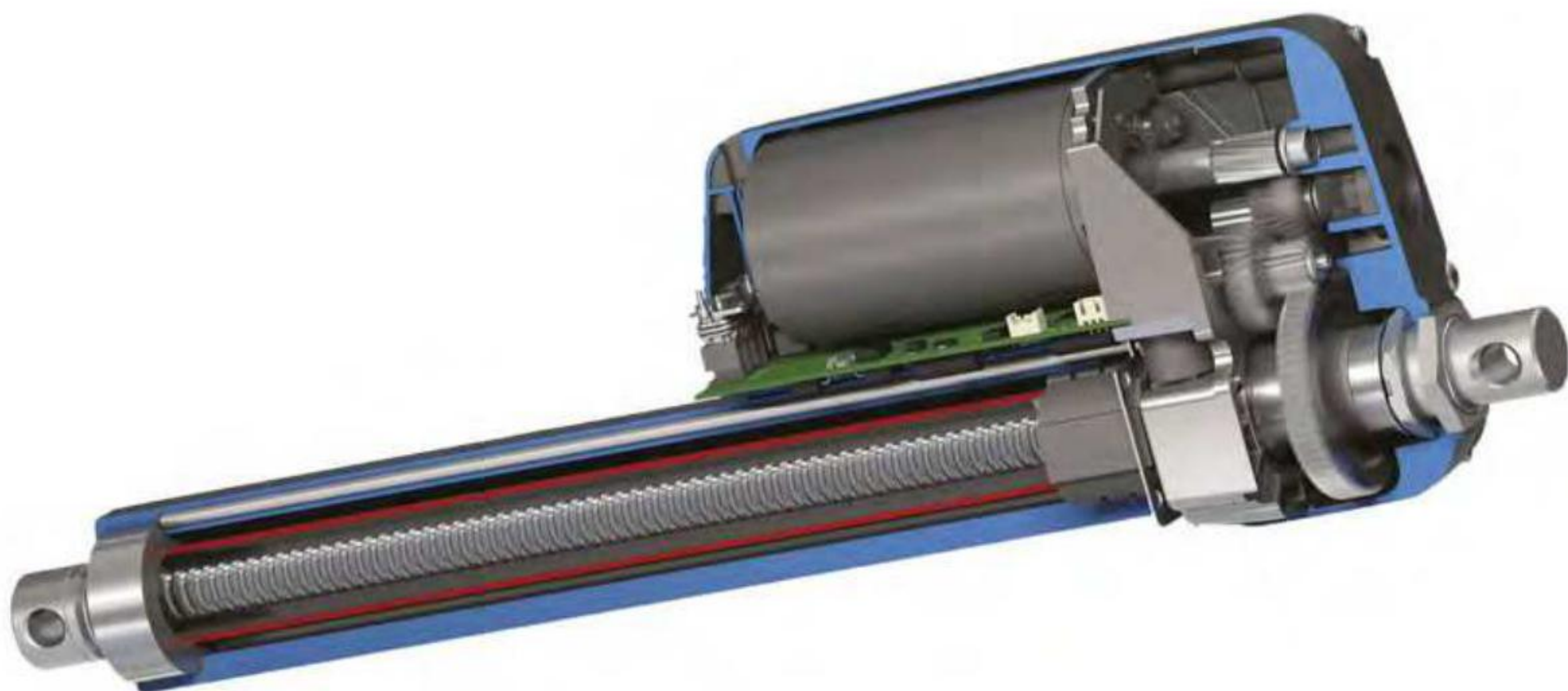


Quick and easy construction

Great results on a low budget

Introduction to linear actuators – Part 1

Automate your gate or curtains, open and close doors and vents, rotate or extend amateur radio antennas – and so much more using linear actuators.



Recently, there's been an explosion in the availability and use of linear actuators – powered devices that extend or retract a rod on demand. These actuators move relatively slowly but with a lot of force. They're used in hospital beds, solar panel trackers, reclining lounge chairs and even to automate the movement of normally hidden TV screens!

From a technical hobby perspective, the list of potential uses is limited only by your imagination. I intend using them to automatically open and shut vents in a solar house. A quick web search will show some amazing uses – from people who have coffee tables disappearing into the floor of their house, to automating the movement of farm gates, to opening attic hatches in the ceiling.

So, what is their design – and how do you control them?

How they work

Linear actuators are typically powered by a brushed, permanent magnet DC motor. (You can find more compact versions with brushless in-line motors and epicyclic gear boxes, but they are much pricier.) Referring to Fig.1, The motor drives a reduction gear-train that is connected to a threaded rod, sometimes called a 'leadscrew'. The rod normally uses a square-cut thread

(like a bench vice) has an internally threaded nylon saddle (a nut) riding on it. The saddle is prevented from turning by a tab sliding within an enclosing tube and is connected to the extension rod. Therefore, when the motor is turning, the saddle



A TV that disappears down into a cabinet! This is a professional system, but you can make something similar using a linear actuator. (Courtesy: Cabinet Tronix)

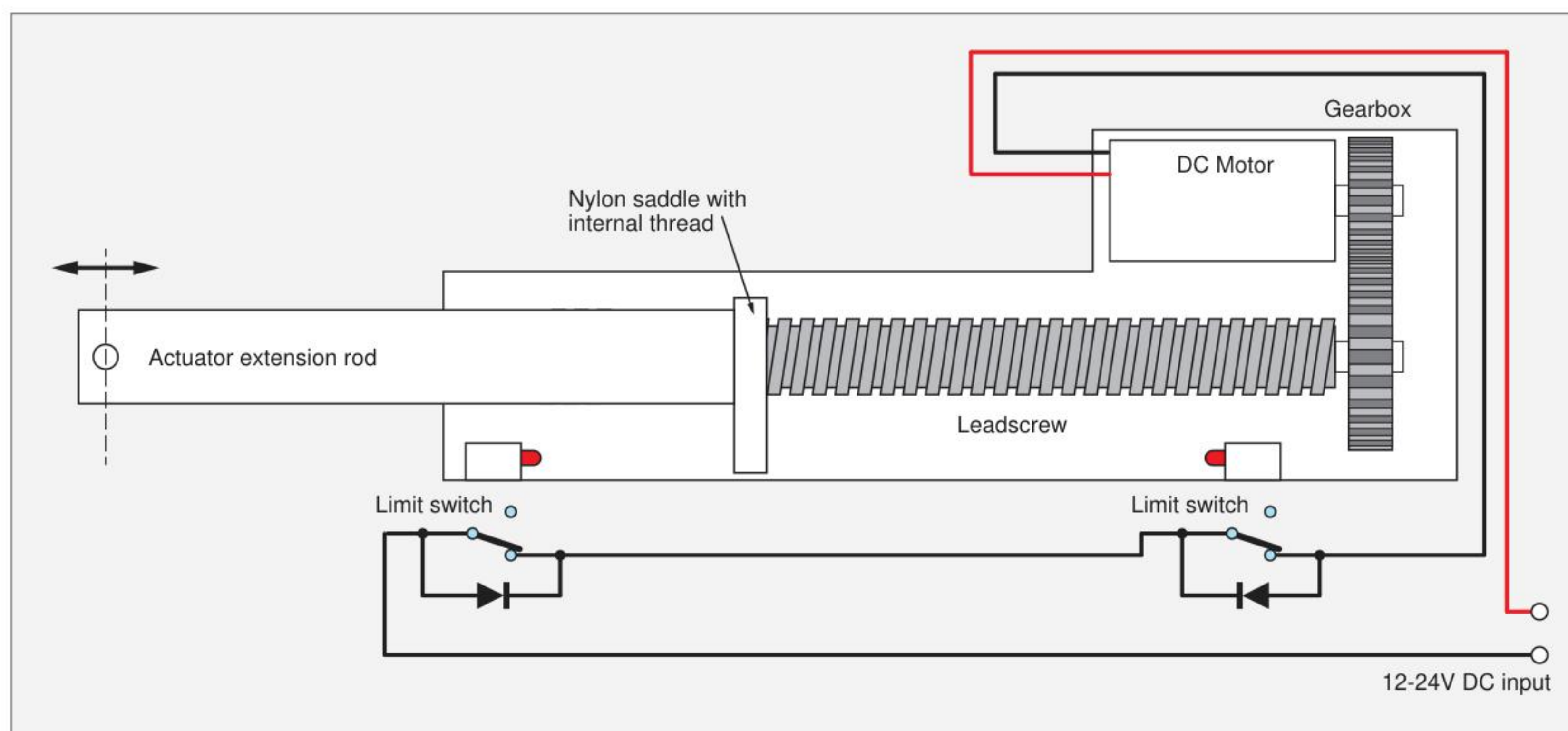


Fig.1. Most linear actuators have in-built limit switches. The limit switches are wired in series, and each switch has a diode wired in parallel with it, with the two diodes wired in reverse polarity to one another. This approach turns off the motor when the actuator reaches the end of the travel, with movement in the opposite direction achieved by reversing the polarity of the power feed. (Courtesy Fircelli Automations)



Linear actuators are now widely available at prices much lower than previously. The actuators use a brushed DC motor, a gear train and a long, threaded leadscrew to power a rod that extends and retracts. (Courtesy: Fircelli Automations)

slowly moves along the threaded rod, extending (or retracting) the rod. The large reduction ratio achieved by the gear-train, and the relatively fine thread pitch of the threaded rod, allows the actuator to develop a lot of force, despite the electric motor being relatively small and its current consumption quite low. With the current switched off, the rod stays locked in position.

The nylon saddle's tab, that prevents the saddle from turning, also has another purpose. It closes a microswitch at each end of the rod's travel, thus turning off power. That is, these limit switches prevent the motor driving the rod so far that it



Neater, but (much) pricier industrial linear actuators are available with in-line brushless DC motors and epicyclic gearboxes. Avoid these unless you really need the extra quality.

hits the end-stops and stalls the motor.

The limit switches are wired in series, and each switch has a diode wired in parallel with it, with the two diodes wired in reverse polarity to one another. (See Fig.1.) This means that, once a limit switch has been tripped, reversing the direction of the actuator requires only reversing the polarity of the motor's electrical connections.

In this way, an actuator can be opened and closed with just a double-pole, double-throw (DPDT) switch.

This can be a normal two-position switch (to fully retract or extend the actuator) or a sprung centre-off switch (to allow the actuator to be stopped at interim positions). With either switch approach, the actuator will be automatically turned off once it's reached full extension or full retraction.

Note that when the actuator is fully extended, it loses some of its lateral (bending) stiffness. This is because the nylon saddle is located right at one end of the enclosing tube, and the clearance between the saddle and the tube results in more lateral movement than occurs when the rod is retracted. Therefore, especially if dealing with high loads, it's best from a mechanical point of view to not completely extend the rod.

Specifications

The main specifications of typical linear actuators are:

- Operating voltage: 12V and 24V are common
- Rod extension: 25-300mm
- Maximum force: 150-800N (×0.1 for approx 'force' in kg)
- Limit switches: Most actuators have one at each end
- Feedback position pot: Far fewer actuators have these
- Weatherproofing: Versions available for outside use.

Industrial linear actuators are very expensive (from £250 and up); however, 'hobbyist-grade' linear actuators from sellers on eBay and companies like Banggood and Aliexpress are much cheaper – starting at about £30. Note also that some companies selling 'branded' actuators are simply reselling the cheap Chinese ones with their sticker slapped on top! In that case, you are paying a premium just for the warranty.

If you intend to use a linear actuator in a demanding industrial use, or it needs to be weatherproof, I suggest that you buy one of the higher price units, but for general household and hobbyist use, the lower price actuators should be fine.

Power supply

The current draw of a linear actuator depends on its size and the load being moved – the current draw increases with both factors. However, the size and mechanical power of linear actuators typically used in hobby and home applications means that a current draw of around 2A is typical for a loaded actuator.

Power can be provided by a suitably rated mains switching power supply (eg, a plugpack) or via a lead acid or lithium-ion battery. Because the duty cycle of an actuator in normal use is very low (how many times a day do you open and close the door of a chicken coop?), renewable energy sources like

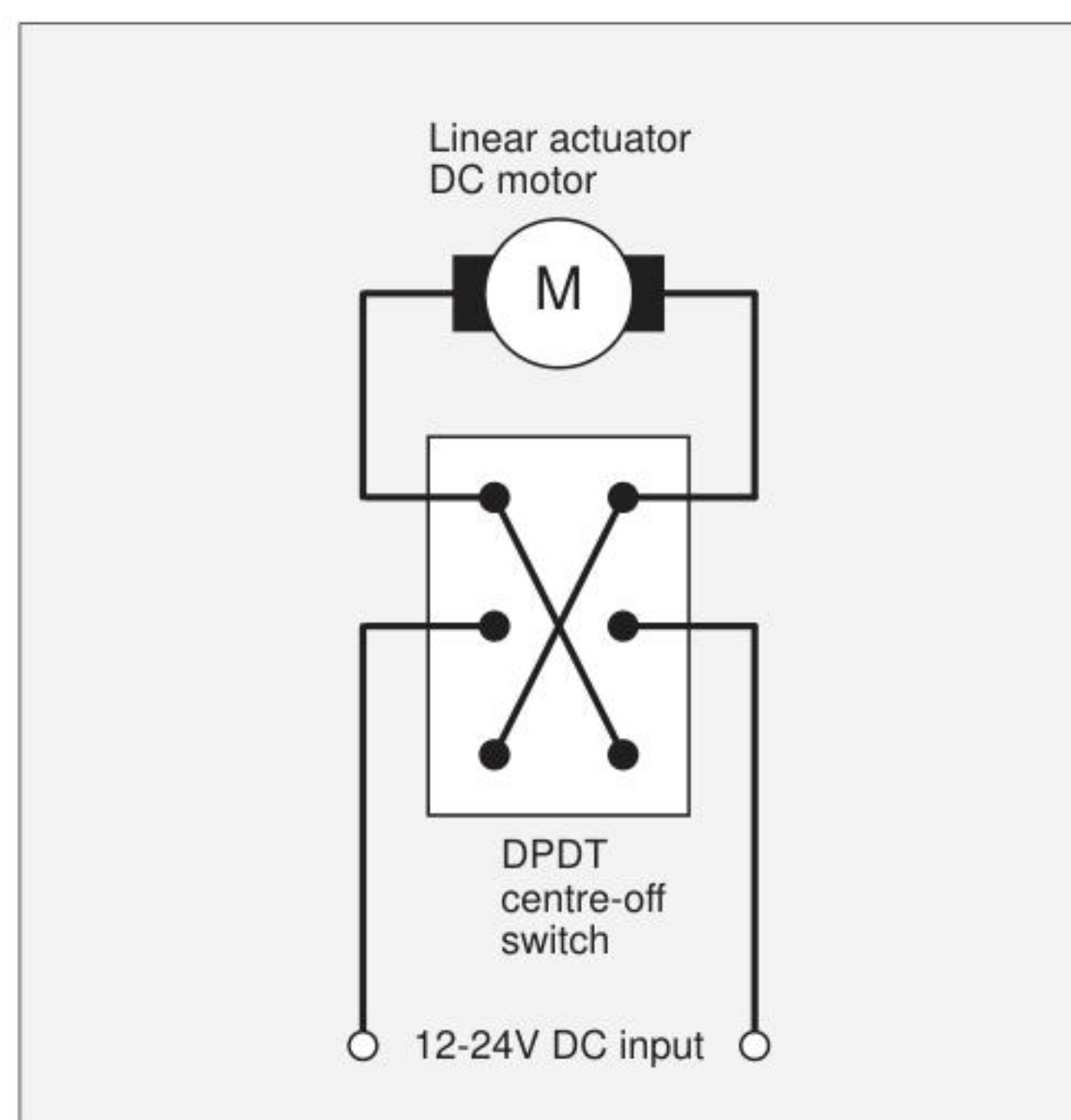


Fig.2. A DPDT switch can be used to manually control a linear actuator. Push the toggle in one direction and the actuator extends, move the toggle in the other direction and the actuator retracts. The presence of in-built limit switches in the actuator prevent damage, even if the switch is held too long in one direction.

solar panels or wind turbines can be used to maintain battery energy levels. This allows the actuator to be located away from mains power.

Switched manual control

The simplest way to control a linear actuator is to use a DPDT, centre-off switch – see Fig.2. When the toggle is moved in one direction, the actuator extends; and when the toggle is moved in the other direction, the actuator retracts. As stated, the limit switches in the actuator prevent damage, even if the toggle switch is held too long in one direction. Because of the relatively low current draw, a normal-duty switch is fine.

If you want to use pushbuttons to control the up and down movements, you can add a diode and a DPDT relay. See Fig.3. Momentary pushbutton 1 feeds power to the linear actuator, with the relay in its normally closed position.

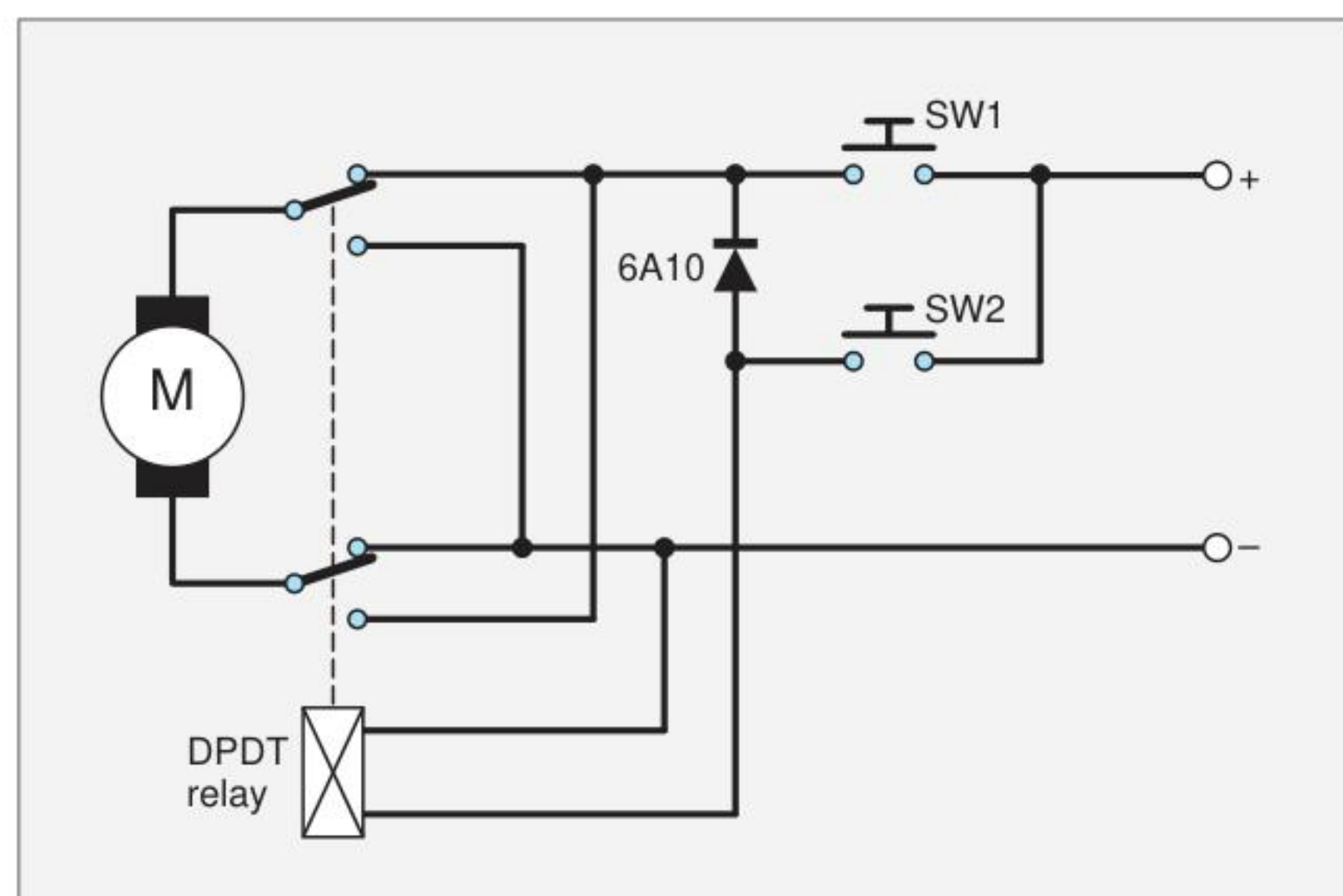


Fig.3. Operation of the linear actuator by two momentary pushbuttons: button 1 feeds power to the linear actuator via the relay in its normally closed position. Pushbutton 2 causes the relay to pull-in, so swapping the polarity of the power feed to the actuator. The diode prevents the relay from operating when pushbutton 1 is pressed.



Linear actuators come with and without position feedback. This unit does not have position feedback – it has only the two power connections. Those actuators with position feedback have an additional three wires for the potentiometer.

Momentary pushbutton 2 feeds power to the actuator but additionally causes the DPDT relay to pull-in, so swapping the polarity of power feed to the actuator and giving reverse direction movement. The diode prevents pushbutton 1 from triggering the relay.

If the actuator is to be fully extended or retracted on each use, the normally open relay outputs of two timer modules can replace the two pushbuttons. To use this approach, measure the time taken for the actuator to extend under load (eg, 30 seconds) and then add (say) 25% for the timed period. When the timer is started, the relay will pull in and the actuator extend. The actuator will stop when it reaches its internal limit switch, and then a short while later, the relay will click off as the timed period elapses. Follow the same approach for the retraction control. Using the timers (rather than say simple latching relays) stops the relays from having to be pointlessly engaged for long periods. The timer modules that you select will need to be of the type triggered by external pushbuttons. Using timers in this manner allows the actuator to be

operated by single press ‘up’ and ‘down’ buttons. Want your TV to rise out of the top of a cupboard? Press the ‘up’ button and walk away. It

will smoothly rise, stopping when full height is reached.

Remote control

If you want progressive remote control of an actuator, an off-the-shelf system is available. It costs under £10 and is available on eBay – search under ‘DC HOUSE Linear Actuator Controller DC8-30V Wireless Remote Motor Control Switch’. (For example, at the time of writing, one of many on eBay is item 313431937657, which is just £7.99, including delivery.) The system operates on 8-30V (the actuator must also use a voltage within this range) and can handle up to 5A.

The controller comprises a receiver/relay module and a remote control with an extendable antenna and two press buttons. The receiver module is fed 12V and in turn feeds the linear actuator. Pressing one button causes the actuator to extend for as long as the button is pressed, or until the actuator reaches full extension. As you’d expect, the other button causes retraction in the same way.

The system is very neat and simple to fit as the polarity changeover and on/off relays and receiver are integrated into one compact module. In testing, the system had a line-of-sight range of over 50 metres – ideal for gate opening and closing.

Safety!

Any mechanical system that uses a linear actuator will need to be stiff and have the required strength to support the loads. Carefully consider what could happen if something breaks – we don’t want people being dumped out of powered reclining armchairs because the forces destroyed the framework!

Don’t use linear actuators to lift heavy weights that are positioned above people, and remember that the actuator becomes less stiff in bending when fully extended.

Remotely opening or closing a door or gate should be done only when it is in view of the operator, otherwise there is the possibility of trapping or squashing people or animals.



(Top) This low-cost remote control is specifically designed for use with linear actuators. The receiver module simply inserts in the power connections to the actuator. Using the remote's pushbuttons allows the actuator to be either fully or partly extended, or retracted.

(Bottom) The inside view of the receiver module showing the two relays and receiver. It's a very neat unit.

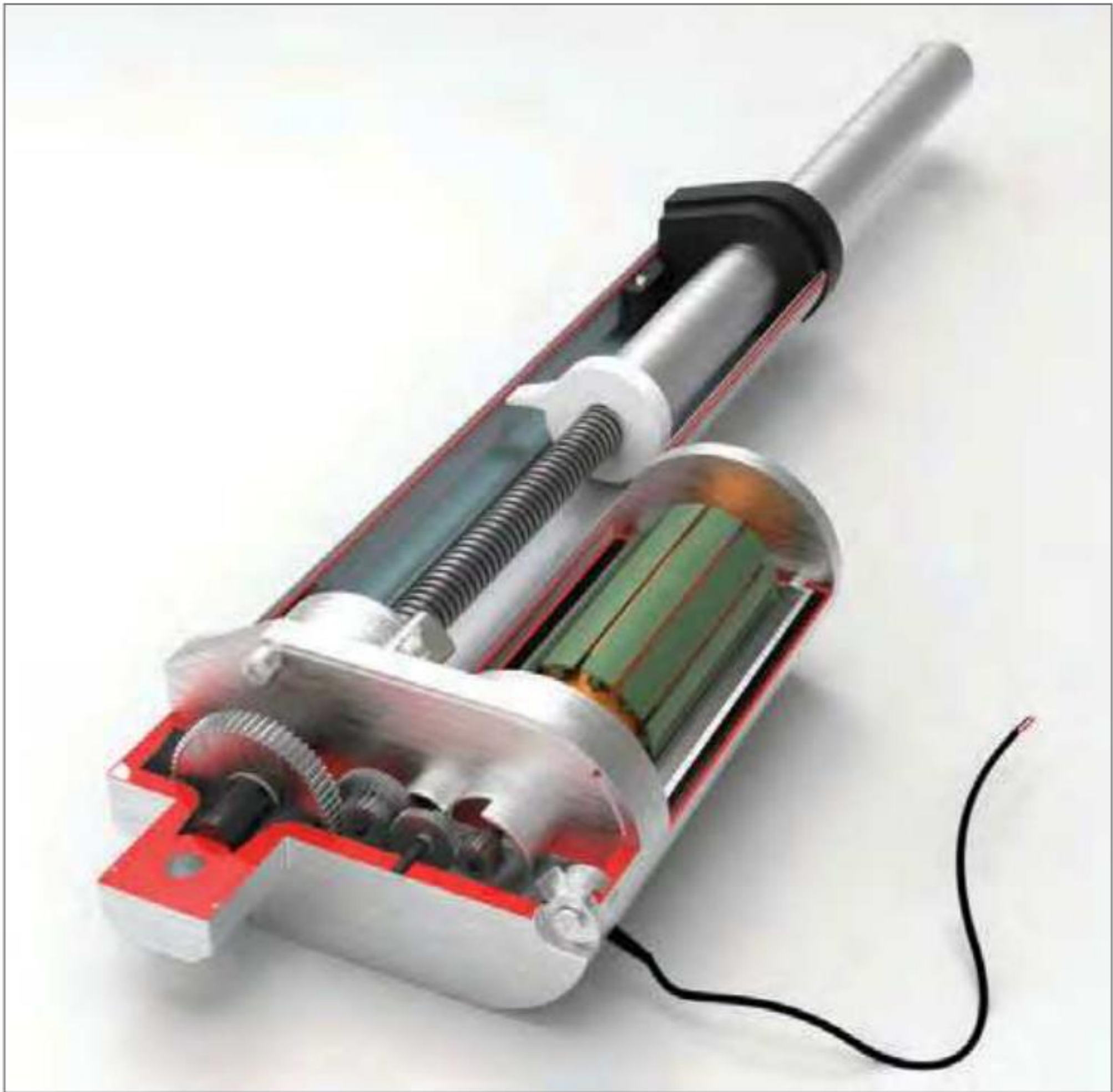
Using a timer to give a specific extension?

If you want to extend and retract the actuator repeatedly to less than full extension, you may think that a timer can be used. For example, using a four-second timed period to extend to the required length, and another four seconds of reverse polarity to retract. But unfortunately, it's no use just operating the motor for a pre-set period and assuming that the rod will end up at exactly position 'X'. Why not? Because these motors are very responsive to voltage changes, even a 0.5V difference in drive voltage will result in the actuator ending up in a different position. The actuator speed for a given voltage also depends on load – another reason you cannot just used a timed period to set the actuator position.

Instead, precise placement of the actuator requires the use of a feedback signal. This is achieved in many linear actuators by using an inbuilt feedback pot – eg, 10kΩ. The voltage signal from the pot then indicates the position of the rod. (Note that actuators with in-built pots usually still have limit switches.) We will cover using this feedback signal in Part 2 in the next issue.

Conclusion

Whether you choose to control a linear actuator with a simple DPDT switch, pushbutton-operated relay or via a remote control, the ready availability and relatively low price of linear actuators means that lots of exciting projects can now become an easy reality.



This cutaway view shows a typical linear actuator. The electric motor is to the right, and the reduction gear train closest to the camera. The lead screw and the white nylon saddle that rides it can also be seen. (Courtesy Firgelli Automations)

In the next issue we will use a sophisticated programmable controller that gives excellent position accuracy of the linear actuator, even with varying voltages and loads. It also incorporates over-current control and allows the acceleration rate of the actuator to be specified.

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Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

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Advanced GPS Computer – Part 2

Our new GPS Computer has a whole host of features and now that we've described how it works, next month we'll move onto the construction and instructions for use. We'll also delve into how the software works.

Single-Chip Silicon Labs FM/AM/SW Digital Radio Receiver

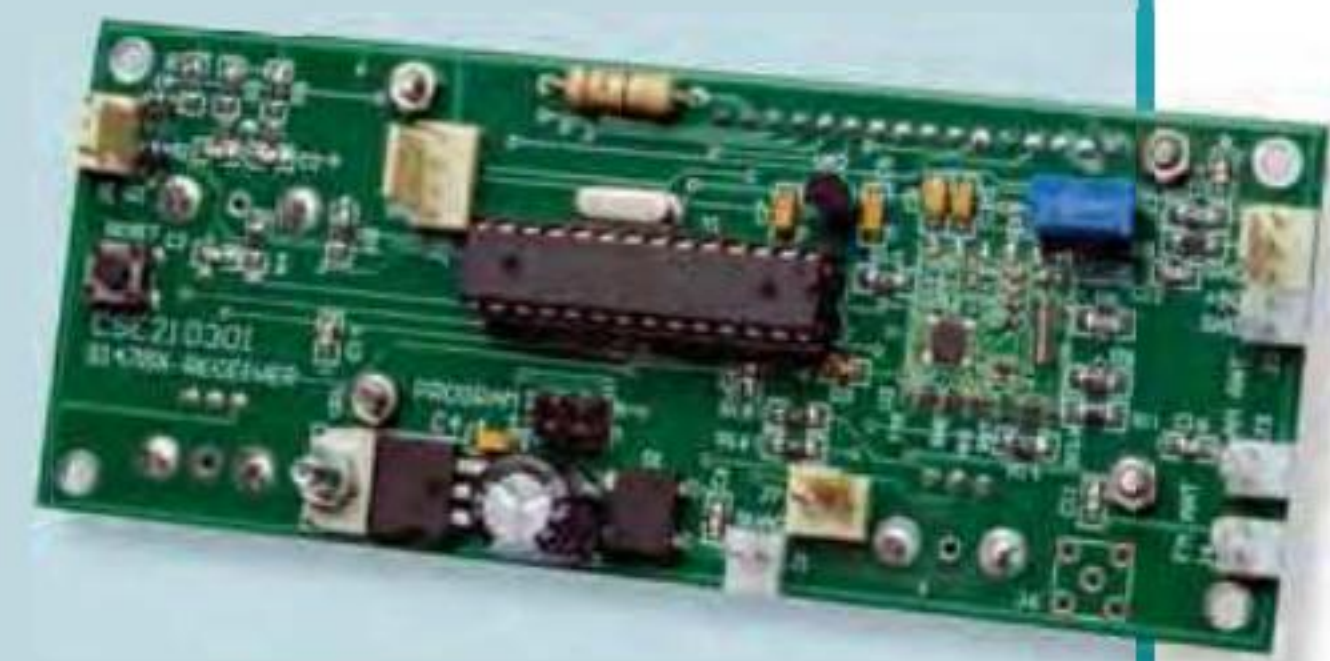
The ultimate in FM/AM radio reception technology is the single-chip solution. All you have to do is connect some antennas to pins on an IC, send it some serial commands, and stereo audio comes out the other end. As a result, ICs from Silicon Labs make building a capable radio receiver a doddle. It's straightforward to set up and use, fits in a compact case and runs from a simple AC plugpack.

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NEW! Peak Atlas ESR70 Gold

Equivalent Series Resistance and Capacitance Meter



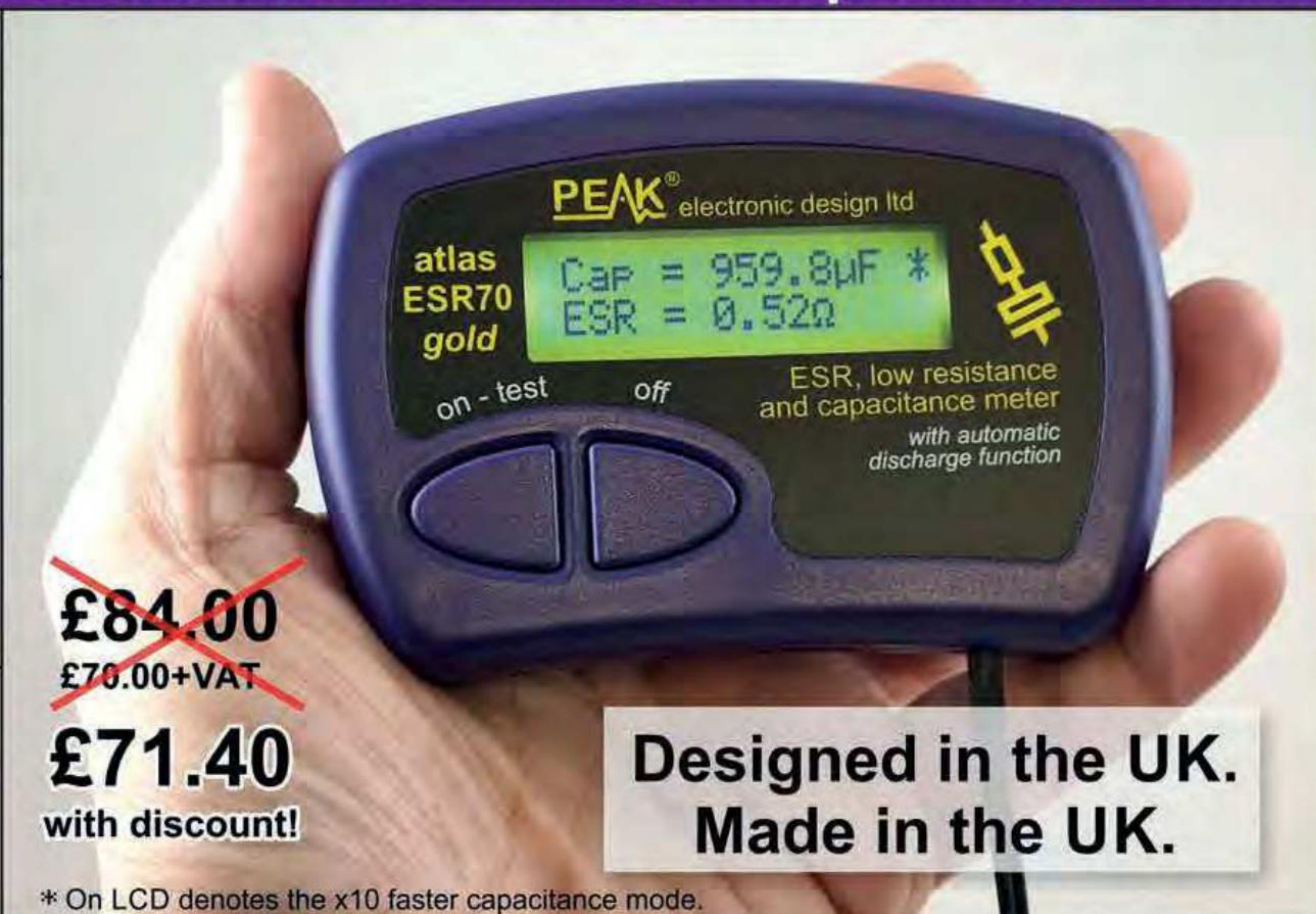
Flexible test leads included



16 page
Fully illustrated User Guide



Optional probe types



~~£84.00~~

~~£70.00+VAT~~

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with discount!

* On LCD denotes the x10 faster capacitance mode.

**Designed in the UK.
Made in the UK.**

What does the new ESR70 Gold do?

The new improved **ESR70 Gold** is great for identifying capacitors (especially electrolytics) that may be suffering from high ESR.

ESR is a great indicator of capacitor condition, especially in applications demanding high ripple currents such as reservoir capacitors, SMPSUs, motor capacitors etc.

The **ESR70 Gold** will even perform a controlled discharge of your caps!

ESR Analysis starts automatically when you apply the probes to the capacitor, even in-circuit.

For out-of-circuit testing, the **ESR70 Gold** also measures capacitance more rapidly than ever.

This **ESR70 Gold** includes removable gold-plated croc-clip probes, long ultra-flexible silicone test leads, alkaline AAA battery and a very comprehensive user guide.

All Peak products carry a 24 month warranty. Even after that period, we offer very low cost repair, update and calibration services.

If you already have an ESR70 that accepts an AAA battery, contact us about having it upgraded to the new Gold spec.

Gold Features

- Much wider capacitance range 0.3µF to 90,000µF (was 1µF to 22,000µF).
- 10x faster capacitance measurement for large capacitors.
- Improved in-circuit accuracy.
- Improved user options system.
- New triple-slope measurement system vastly reduces the influence of parallel resistance and leakage current on capacitance readings.

Summary Specs

- ESR measurement from 0.00Ω to 40.0Ω. Can be used for simple low-ohms testing too.
- Audible alerts for different ESR levels.
- Automatic controlled discharge before analysis.
- Automatic and manual power-off.
- New backlit display.
- Very long battery life from a single AAA cell.